U. S. Aero Medical Research
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Physiology of Flight

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PHYSIOLOGY OF FLIGHT

Human Factors in the Operation of Military Aircraft

A COMPENDIUM OF LECTURES AND DEMONSTRATIONS GIVEN TO ARMY AIR FORCE PERSONNEL

1940 - 1942

BY

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Foreword

The material presented in this booklet is, for the greater part, a condensation and epitome of lectures presented to Army Air Forces flight and medical officers in "high altitude physiology." The instruction was initiated in January, 1941, and has been intermittently carried out to date. The original concept in giving the instruction was to insure the proper use of oxygen equipment, to explain the physiologic changes that occur or might occur at high altitude, to describe known methods of alleviation of the ill effects of low barometric pressure when prevention or amelioration is effective, and to correct the misconceptions that are prevalent.

This compilation of papers on various subjects in aviation medicine is, obviously, not a complete treatise—nor is it intended to be. The material presented has been selected as being the most useful and necessary in the high altitude training and indoctrination program. One revision has already been necessitated by experience gained in the training courses and by changes made in equipment.

It is recommended that texts, monographs, and special articles on aviation medicine be consulted for more complete information.

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Introduction

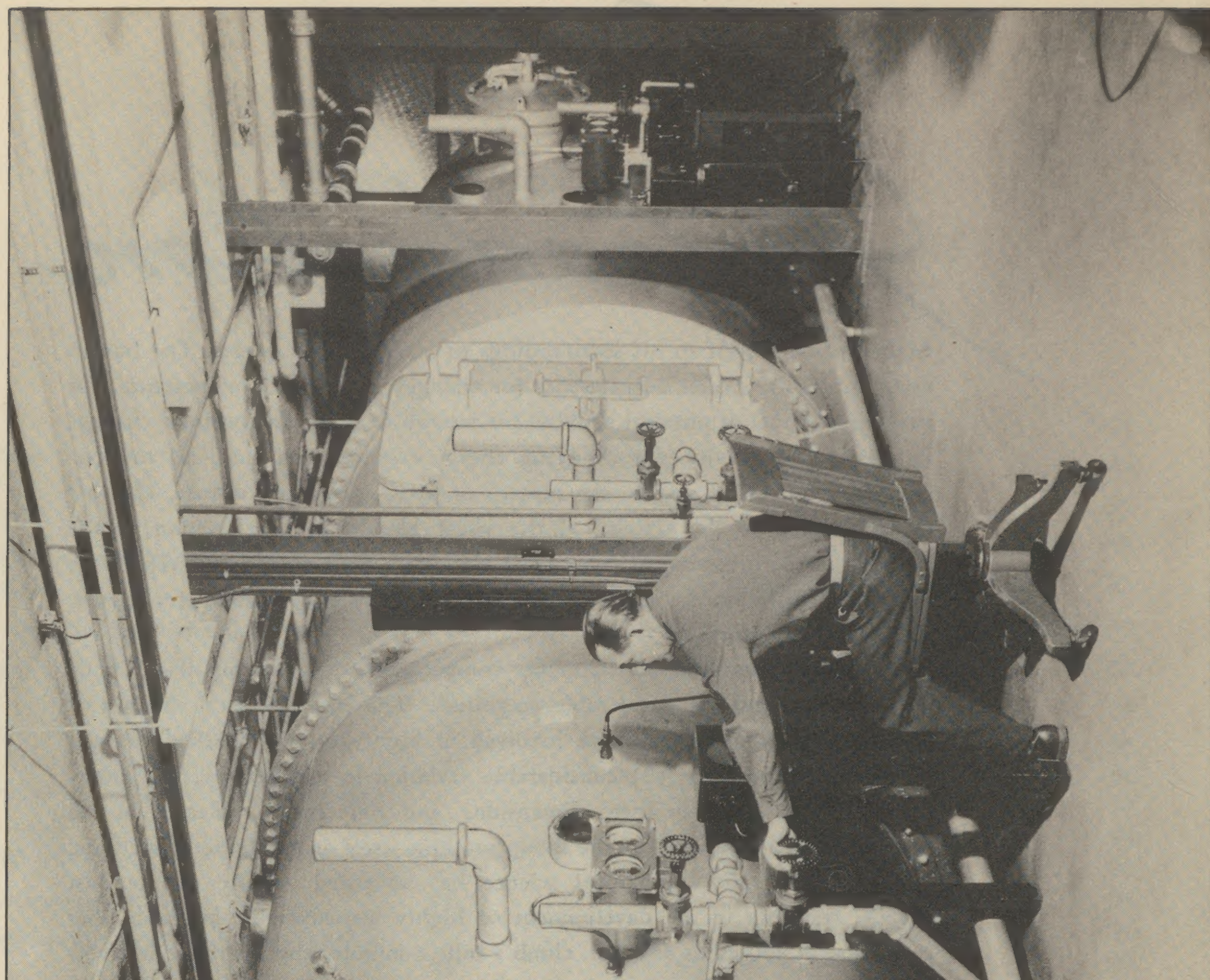
Man adjusts himself to his surroundings to a remarkable degree. The human body constantly makes adjustments for changes in external temperature, for varying amounts of physical activity, for motion in space, for postural changes in relation to gravity, for changing energy requirements, and, all too frequently, adjustments against the inroads of toxic agents and disease. Changes in respiration, in the activity of the sweat glands, in the function of the kidneys, in the ingestion of food, or in the desire for rest or physical activity, all tend to maintain the internal environment of the body within very narrow limits of fluctuation.

In aviation the demands upon the compensatory mechanisms of the body are numerous and of considerable magnitude. The environmental changes of greatest physiologic significance involved in flight are: (1) marked changes in barometric pressure, (2) considerable variation in temperature, (3) movement at high speed in three dimensions, and (4) change reflected in the mechanical characteristics of the flying machine itself as an abode or medium.

Aeronautical and mechanical science has advanced rapidly in the past decade, resulting in the development of highly maneuverable airplanes that can cruise at 400 miles an hour, climb a mile a minute, and operate effectively at 30,000 feet or higher. It is obvious that man cannot operate these machines at full capacity without physical aids such as an artificial supply of oxygen and pressurized equipment for use at extreme altitudes. Sharp turns or pull-outs from dives at high speed cause centrifugal effects, many times the normal effect of gravity, leading to unconsciousness if the effects are prolonged.

Man, then, as a flying creature must overcome the handicaps imposed by nature on an organism "designed" for terrestrial life. The necessary aids are largely mechanical. It behooves flyers to understand the mechanical characteristics of their machines but, likewise, they must know the functioning of the human body under the special conditions imposed by flight. In particular, the limiting factors in adjustment of the human body to flight must be appreciated. The extent to which these limiting factors are alleviated by available equipment must be clearly understood. Indifference, ignorance, and carelessness can nullify the foresight, ingenuity, and effort involved in the supplying of efficient equipment. The ultimate result is failure of missions and unfortunate experiences by personnel.

An effort is made in the following pages to outline the important factors in the physiology of flight and to describe the devices that contribute to the welfare and tactical efficiency of flying personnel.



Exterior View of Low-Pressure Chamber at Wright Field Showing Controls and Instruments

CHAPTER I
THE TACTICAL ADVANTAGES OF FLYING AT HIGH ALTITUDES

Distance

IMMUNITY TO ANTI-AIRCRAFT FIRE.—The first and most obvious advantage of high altitude flying is one of distance. The effectiveness of anti-aircraft fire depends upon the distance of the target from the gun. The greater the distance, the lower the accuracy of the fire. The range of fire for a particular gun is limited. Therefore, if the target is moving at an altitude beyond that limit, anti-aircraft fire is ineffective.

FREEDOM FROM INTERCEPTION.—The primary objective in a bombardment or reconnaissance mission is completion of that mission. The objective of a bombardment flight is to reach and attack the target, and the objective of a reconnaissance mission is to reach the particular area involved, obtain the information necessary, and return safely. Interception before completion of the mission may cause its failure. The higher the altitude of operation, the greater is the time required for interception by hostile aircraft. This time required for interception should be enough to allow completion of the mission. Obviously, protecting fighter aircraft may be used without the advantage of altitude. Even under these circumstances, altitude, in addition to the fighter protection, increases the likelihood of success.

Interception assumes detection. There are several methods of detection. The first and simplest is direct detection, with the unaided eye. Obviously, the higher the altitude, the more difficult detection will be. The same applies to the use of magnifying devices, such as field glasses. The effectiveness of sound devices depends upon their degree of accuracy. The accuracy of these devices becomes less with increasing altitude. Intervening weather conditions reduce the accuracy still further. Intervening cloud formations or fog occasionally makes direct visual detection impossible. At first glance, radio detection appears to surmount all these difficulties. Yet radio detecting equipment operates with radio waves which are fundamentally the same as any normal radio waves or light waves. The characteristics, of course, depend more or less upon the wave length. The higher the altitude of operation, the more intervening weather factors may introduce errors into radio detection. These errors may be caused by reflection from cloud layers or from electrical disturbances. It can be seen that, from the point of view of detection, there are definitely great advantages to flying at high altitudes.

The question may be raised as to how the objective may be reached if altitude operation is performed under certain weather conditions that prevent or render inaccurate detection of the target. Bombardment of a target made invisible by cloud formations normally is not practicable, but the major portion of the flight can be made over the top of the formation, and the target can be attacked after a descent through the cloud overcast, or in a clear area at the target if the weather happens to be so favorable. An item in sound detection that may be of some importance is the time required for sound to travel from the airplane to the ground. The speed of sound, on the average, is 1,000 feet per second, so a delay of one second will result for each 1,000 feet above the ground a plane ascends.

The factor which acts contrary to the advantages of high altitude in regard to detection is the development of vapor trails. At altitudes of more than 20,000 feet, under normal temperature conditions, these trails may form by condensation of the water in the exhaust gases from the engines. The density and duration of a vapor trail depend upon the atmospheric conditions, the power, and the speed of the aircraft concerned. However, in general, when airplanes are equipped with high-performance engines and fly at altitudes of more than 25,000 feet, vapor trails may be expected to form under all atmospheric conditions. This subject is considered more fully in the next chapter.

Another means of detection, particularly for night operation, is the radiation of infra-red rays and visible radiation of hot parts of the engine. Obviously, the higher the altitude, the more difficult this type of detection will be. It may be further complicated by intervening clouds.

Relative Performance

AIRPLANE AND ENGINE.—In operation at high altitudes, the relative performances of the attacking aircraft and the intercepting or protecting aircraft must be borne in mind. It is advantageous not only to operate at altitudes at which performance of enemy aircraft is not superior, but also to utilize altitudes at which the margin of performance of the enemy aircraft is at a minimum. If the maximal altitude at which normal power can be maintained is higher than that of all ene-

my aircraft that may be encountered normally, it is disadvantageous to operate above this maximal altitude. There is a secondary factor in this consideration which must not be overlooked; namely, even though the performance may be inferior to that of enemy aircraft, operation at high altitudes may involve sufficient delay in interception on the part of the enemy to make operation at such altitudes advantageous.

EQUIPMENT.—When an airplane operates at high altitudes, the performance of not only the airplane and its engines, but also that of all its equipment, must be considered. This equipment includes oxygen equipment, supercharged cabin, pressure suit, heating, defrosting and oil lubricating systems, ignition and electrical systems, lubrication of equipment, armament, and the like, and all items that may be affected by low pressure, low temperature, or their combination must be included. Obviously, if such items of equipment provide superior performance in function to those of the enemy at high altitudes, it is advisable to take advantage of this superior performance; conversely, if the equipment of the enemy has superior performance at high altitudes, such disadvantages should be avoided by operation as much as possible at altitudes in which equal performance is obtained. For example, an airplane equipped with a supercharged cabin that has high performance at altitudes in the vicinity of 45,000 feet should have a very definite advantage over enemy aircraft not se equipped for operation at high altitudes.

APPROACH.—The advantage of performance in the interception of hostile aircraft by approach from above is generally well known. It yields superior performance in speed during the attack, and may allow the important advantage of surprise.

Speed for Maximum Range

Assuming still air, maximum range is a function of the height at which a particular power plant-airplane combination can support the aircraft efficiently in flight. Many factors are involved, some of which have not fully been reduced to simple calculations without an experience factor and final confirmation in actual flight. However, the loss in range which may accompany an increase in altitude usually is negligible, particularly if considered in relation to the gain in speed and reduction in time required for the performance of the mission by operation at high altitudes. For example, the true air speed for maximal range at 40,000 feet is about twice that at sea level. If the speed for maximal range at sea level is 150 miles per hour, the speed for maximal range at 40,000 feet is approximately 300 miles per hour. This means that the time required for performance of a mission at 40,000 feet is half that required at sea level. This factor is of great importance in regard to the success of the mission as affected by the fatigue of airplane crews.

Favorable Winds

The magnitude of wind velocity in general increases as altitude increases. Therefore, the increase in speed obtained from favorable winds may be maximal at high altitudes. Aircraft with good performance at high altitudes allow considerable flexibility in this regard, in that the most favorable levels with regard to the wind can be selected in each direction.

Flying Over Bad Weather

Operation at high altitudes has a distinct advantage in so far as the weather is concerned, for in many cases it may be possible to conduct the major portion of the mission "over the top" of bad weather conditions. This is an advantage to the final success of the mission, since it makes it possible to avoid the scattering of formations that otherwise would result from flying in bad weather and it minimizes the fatigue, which always accompanies operations carried out in bad weather.

Reconnaissance

The advantage of flying at high altitudes in reconnaissance should be obvious, but might be overlooked. Operation at low altitudes might result in inability to see the general aspects of the ground operations, because of inability to see more than details. In other words, it may be impossible "to see the forest because of the trees." The higher the altitude, the more the earth's surface becomes a relief map. At extremely high altitudes, the entire field of operation can be seen at a glance.

Surprise

The possibility of surprise in attack is maximal during operations at high altitudes. It is an important factor in the interception of hostile aircraft, and in the attack upon ground targets. Surprise is one of the greatest elements of advantage in warfare. Of course, the advantage of surprise which results from flying at high altitudes does not preclude advantageous flights at extremely low altitudes under certain conditions. Flight at extremely low altitudes obviously, in some cases, has advantages over flight at extremely high altitudes; but on missions in which flight must be maintained above the minimum, the greater the altitude the greater the element of surprise will be.

CHAPTER II
THE PHYSICAL CHARACTERISTICS OF THE ATMOSPHERE

The purpose of this chapter is to review briefly certain physical factors of our atmosphere that are important to the physiology of the flyer. The liberty of digressing from this primary intention will be taken whenever general interest in the subject may be broadened to the advantage of the reader.

Temperatures in the Upper Air

Let us begin the discussion by examining briefly the average distribution of temperature in the upper air over the earth's surface. Probing of the temperature of the upper atmosphere by means of radio sonde balloons has been in progress for the past twenty years. The highest sample taken thus far was obtained at the 22-mile level above the earth. On the basis of collected readings of temperature taken at various latitudes in different parts of the earth, we may state the following generalities with reasonable reliability:

1. The upper atmosphere is divided into two spheres: (1) the *troposphere,* which immediately surrounds the earth and (2) the *stratosphere,* which in turn surrounds the *troposphere.*

2. The *troposphere* is characterized by a surprisingly constant rate of decrease in air temperature as the height above the earth increases.

3. The *stratosphere* is characterized by a fairly uniform temperature which varies little with altitudes.

4. The boundary between the troposphere and the stratosphere is called the *tropopause.*

5. All our weather phenomena occur in the troposphere, for they are inherently associated with the physical properties of temperature gradient and moisture content.

6. The height of the tropopause varies with latitude. It is closest to the earth at the pole (approximately 6 miles) and the farthest away at the equator (approximately 10 miles).

7. The temperature of the stratosphere varies with latitude. The warmest stratosphere temperatures occur over the poles, where temperatures as warm as −40 degrees C (—40 degrees F) may exist. The coldest stratosphere temperatures occur over the equator, where temperatures as low as —80 degrees C (—110 degrees F) have been observed.

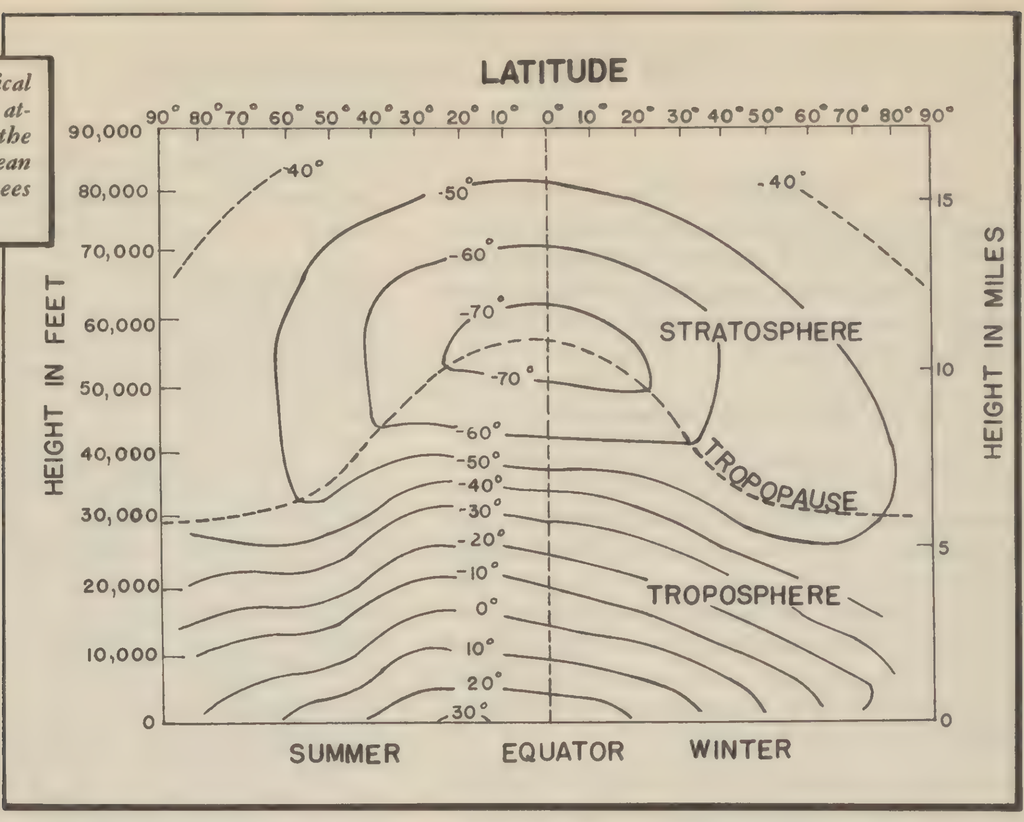
8. Over the equator, at still greater heights, a reversal of the temperature gradient has been observed.

The above facts are consolidated in figure 1, which somewhat idealizes the situation. This figure does not include the effects of the oceans and the continents, which obviously will cause further variation from longitude to longitude.

It is hardly within the scope of the present discussion to attempt a thorough scientific explanation of the observations indicated in figure 1, but a few fundamental physical principles associated with temperatures of the upper air should be pointed out. The origin of all terrestrial heat is the "short-wave" radiation from the sun. With the exception of the radiation absorbed by clouds, this radiation is not absorbed in the atmosphere but at the earth's surface. All temperature phenomena in the atmosphere and in the troposphere are caused by the presence of water vapor and its absorption of "long-wave" radiation from the earth. Near the earth's surface a body of air can absorb, by radiation from the earth, eleven times the heat it would lose by re-radiation to other bodies of air and the heavens. When a body of air heats, it tends to rise. As it rises, it expands because of decreasing atmospheric pressure. Since expansion is done adiabatically, this body of air cools and precipitates part of its moisture content to form clouds. As this air mass cools further, its moisture falls and hence its heat absorption of long-wave radiation from the earth decreases. By repeated cycles of the above physical phenomena, which we commonly know as "weather," relatively constant stratosphere temperatures of approximately—55 degrees C are finally reached. where for a body of air the water content is so low that a balance exists between the absorption of earth radiation and the re-radiation to the heavens. Here, a region of constant temperature with altitude is found to exist (that is, the stratosphere).

Regular changes in atmospheric temperatures from day to night are observed only up to a height of approximately 3,000 feet above the ground. In general, temperatures of the upper atmosphere have no diurnal variation. Seasonal variations and variations caused by passing high and low pressure cyclonic areas do change the temperature of the upper air. For example, over San Diego, California, at the 40,000-foot level, atmospheric

Figure 1. — Vertical section through the atmosphere, showing the distribution of mean temperature in degrees centigrade.



temperatures in the range —40 degrees C to —80 degrees C have been observed. In fact, temperatures as low as —80 degrees C are not uncommon at the 40,000-foot level. Temperatures at levels of about 20,000 feet above the tropopause into the stratosphere, however, usually are very stable the year around.

In general, it may be stated that temperatures of the upper air decrease steadily with increasing altitude to their constant stratosphere value. However, near the equator an increase in temperature is known to exist about 15 miles above the earth. At the latitude of Wright Field this temperature inversion probably lies at the 22-mile level. From observations on the reflection of sound by the upper atmosphere it has been calculated that temperatures of the upper air increase to as high at 177 degrees C at the 40-mile level above the earth. This temperature, however, is only of academic interest for the present; but for those interested, in figure 2 a speculative graph is presented in which temperature variations in the extreme upper atmosphere are shown as they are believed to exist on the basis of present theory.

Temperature inversions also have been observed near the earth's surface. For example, at the polar regions this inversion is very pronounced. At Ladd Field, Alaska, in the winter time, ground temperatures of −40 degrees C to —45 degrees C are not uncommon, while at the 8,000 foot flying level temperatures as high as —5 degrees C may simultaneously exist. It is a novel fact that extreme cold (that is, less than −40 degrees C) usually is met by the aviator either on the ground or in the stratosphere, but practically never at 10,000 feet, regardless of the longitude and latitude.

The most important physical property of the upper atmosphere to the pilot, in the physiologic sense, is the actual pressure of the air in which he flies. Our well-being and our ability to think and to reason are inherently dependent on the partial pressure of oxygen we breathe, as we shall see in chapter III. This partial pressure in turn is dependent solely on atmospheric pressure. It is therefore essential that we know the ambient pressure in which we fly. For this knowledge we must rely on the altimeter, which by means of a calibration factor describes a given pressure in terms of so many feet.

Since it is very convenient to describe a pressure in terms of feet, let us examine the basis for the present calibration of our Army Air Force altimeter, and see how the three technical altitudes familiar to all pilots, namely, the "pressure," the "density," and the "tapeline," altitudes are related to each other and our physiologic well-being.

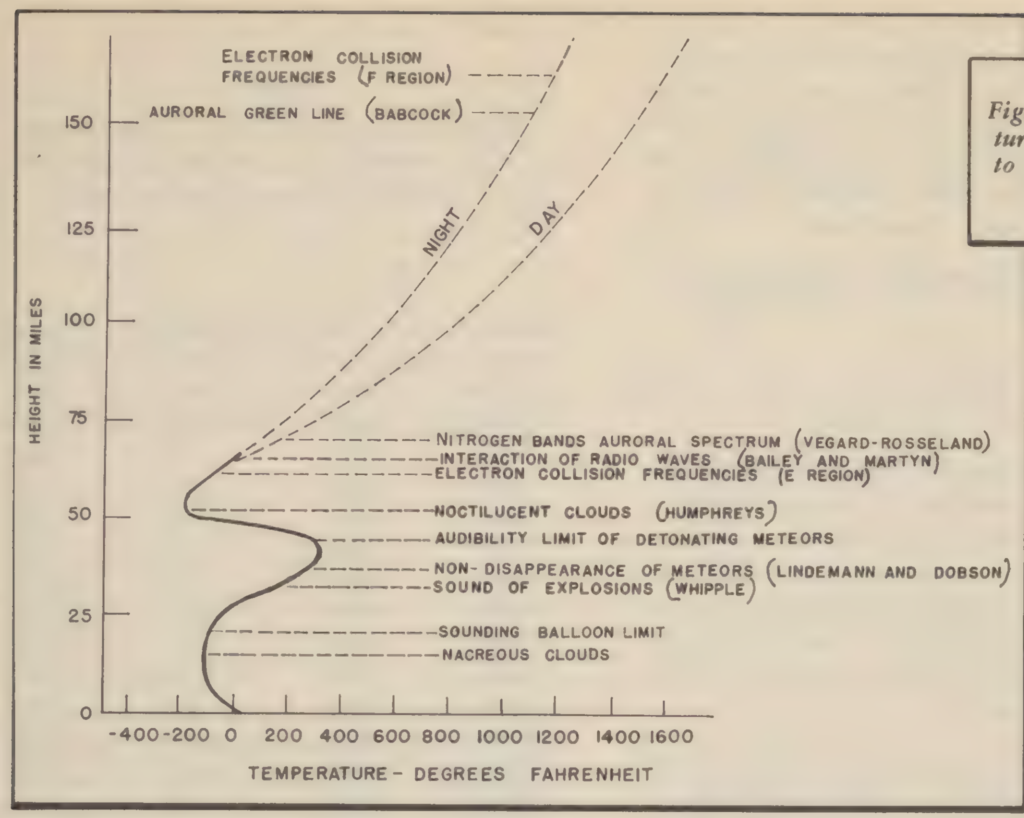


Figure 2. — Temperature of the atmosphere to great heights (Martyn and Pulley).

The United States Standard Atmosphere

The calibration of an altimeter is the problem of giving an interpretation in feet or meters for a given pressure in millimeters or inches of mercury. The pressure of the ambient air is a relatively simple measure-a well-known theorem of LaPlace, for a column of air ment, but its calibration in feet is mainly theoretic. It is of uniform temperature and of infinite height subjected to the field of gravity, that at any point the height varies linearly with the logarithm of the pressure. By assuming appropriate constants and assuming a uniform temperature of 15 degrees C for the column, such a calibration between pressure and altitude can be constructed. The assumption that the column of air is of uniform temperature in itself is invalid, and leads to altitude values in feet considerably higher than those found by actual survey methods from the ground.

In 1924, the Weather Bureau, in conjunction with the Bureau of Standards, devised the present United States Atmosphere. Experimentally, it was found that at a latitude of 40 degrees in the United States, the temperature decreased linearly with altitude until the height of about 35,000 feet was reached, at which the temperature became constant with altitude. With this experimental fact as a basis, the United States Atmosphere is founded on the following assumptions:

1. The temperature decreases linearly with altitude until the isothermal atmosphere begins, the gradient vanishing at the lower limit of the isothermal atmosphere, that is at 35,332 feet.

2. The temperature of the isothermal atmosphere is —55 degrees C.

3. The air is dry.

4. The air is a perfect gas, obeying Charles and Boyle's Laws.

5. Gravity is constant at all altitudes.

Some physical properties of the United States Standard Atmosphere are given in table 1, in which altitudes extending up to 60,000 feet are presented. At sea level the standard pressure and temperature is 760 millimeters (29.92 inches) of mercury and 15 degrees C. The temperature decreases at a uniform rate of about 19.8 degrees C for each 10,000 feet altitude, until the altitude 35,332 feet is reached, at which the isothermal atmosphere of —55 degrees C begins. For each altitude in feet the corresponding pressure in millimeters of mercury is given. This relationship is the official calibration

curve for all the altimeters in current use in all Army Air Force aircraft; but it is not used internationally. In the last column the density ratio is given. It represents the ration of the actual density of the air at a given altitude to that at standard sea level conditions. The density ratio is thus calculated from the relation (derived from Charles' Law): Density ratio =

$$\frac{\text{Pressure in mm. of Hg. at A feet}}{760} \times \frac{(273+15°C)}{(273+T°C_A)}$$

hence, density ratio $= \dfrac{0.3789 \times P \text{ (in mm. Hg.)}}{T\text{ (°C ABS)}}$ (1)

One sees that the atmospheric pressure decreases to half value at 18,000 feet, whereas the density decreases to half value at 21,500 feet. The pressure is a fourth at 33,500 feet, while the density ratio is only a third at 33,000 feet. Tables giving the complete properties of the United States Standard Atmosphere may be found in publications No. 218 and 538 of the National Advisory Committee for Aeronautics.

Aerodynamically, the speed of the airplane, the pull of the propeller, the lift of the wing, and even the trajectory of the bomb are judged not in terms of pressure altitude (the actual reading on the altimeter) but by performance in air of equivalent density and viscosity. For this purpose a term "density altitude" is used as the independent variable on which all aerodynamic properties during flight are based. On the other hand, the horsepower delivered by the engines of an airplane is not a function of density, but of the actual pressure of the outside air; that is, of altimeter reading itself. Let us make clear the distinction between *density* and *pressure* altitudes.

The *density altitude* as used by the flight engineer is calculated as follows:

1. The altimeter reading and observed temperature of outside air are recorded.

2. From the altimeter calibration chart (table 1) the true barometric pressure is known.

3. The observed barometric pressure and the observed outside temperature are used to calculate by equation the density ratio for that particular level (1).

4. The *density altitude* corresponds to the Standard Altitude having the same density ratio as the calculated ratio in (3) above.

TABLE 1

SOME PROPERTIES OF U. S. STANDARD ATMOSPHERE (TAKEN FROM N.A.C.A. REPORTS, No. 218 and No. 538)

Altitude, feet	*Pressure, mm of Hg*	*Temperature,* °C*	*Density ratio*
0	760.0	15.0	1.000
2000	706.6	11.0	.9428
4000	656.3	7.1	.8881
6000	609.0	3.1	.8358
8000	564.4	– 0.8	.7859
10000	522.6	– 4.8	.7384
12000	483.3	– 8.8	.6931
14000	446.4	–12.7	.6499
16000	411.8	–16.7	.6088
18000	379.4	–20.7	.5698
20000	349.1	–24.6	.5327
22000	320.8	–28.6	.4974
24000	294.4	–32.5	.4640
26000	269.8	–36.5	.4323
28000	246.9	–40.5	.4023
30000	225.6	–44.4	.3740
32000	205.8	–48.4	.3472
34000	187.4	–52.4	.3218
35332	175.9	–55.0	.3058
36000	170.4	–55.0	.2962
38000	154.9	–55.0	.2692
40000	140.7	–55.0	.2447
42000	127.9	–55.0	.2224
44000	116.3	–55.0	.2021
46000	105.7	–55.0	.1838
48000	96.05	–55.0	.1670
50000	87.30	–55.0	.1518
52000	79.34	–55.0	.1379
54000	72.12	–55.0	.1254
56000	65.55	–55.0	.1140
58000	59.58	–55.0	.1036
60000	54.15	–55.0	.0941

*NOTE: All instruments on dash boards of modern U. S. aircraft have a temperature calibration in centigrade—not in Fahrenheit.

Actually, in flight every pilot is equipped with an "Aero Dead Reckoning Slide-rule—Dalton Model B," which, among many other diverse scales, can be used to calculate the *density altitude* from the observed altitude meter reading and observed outside temperature. Typical examples of the relationship of *density altitude* to *pressure altitude* and air temperatures are given in table 2.

Examination of table 2 shows that:

1. The *pressure altitude* (reading on altimeter) equals the *density altitude* when the outside temperature equals the corresponding temperature for the Standard Atmosphere.

2. For every degree centigrade the temperature of the outside air is above the standard temperature, the *density altitude* is approximately 100 feet above the *pressure altitude* (altimeter reading); also, for each degree below the standard, the *pressure altitude* is 100 feet below the *density altitude*.

Careful observation by triangulation with telescopes from the ground has shown that *density altitude* is much closer to being the true altitude above the ground than is the *pressure altitude*. In teaching navigation to new pilots, it is customary to emphasize the temperature correction that must be imposed on the actual altimeter reading. In reality, this correction is simply a calculation of the *density altitude,* which is believed to be the closest to the true "tapeline" altitude above the ground.

It should be emphasized to all pilots who participate in high altitude flights, that all criteria for the use of oxygen equipment and the probability of their having "bends" and anoxia depends on the actual reading of the altimeter in the airplane and not on the true height above sea level. To the physiologist and the flight surgeon the importance of distinguishing between *pressure* and *density* or "tapeline" altitude lies in interpreting properly flight records in the range of 35,000 feet to 45,000 feet. In this range, as will be shown in chapter III, the physiologic response of the human body changes rapidly in terms of feet. An error in judging the numerical altitude by 2,000 or 3,000 feet makes a great difference in the reaction of a pilot to his environment. It should always be remembered that:

1. Aerodynamically, airplane performance is judged in terms of *density* or "tapeline" altitude.

2. Physiologically, human performance is judged by the actual reading on the altimeter.

TABLE 2

THE RELATIONSHIP OF DENSITY ALTITUDE TO PRESSURE ALTITUDE AND AIR TEMPERATURE: TYPICAL EXAMPLES

Density altitude, feet	*Temperature °C*	*Pressure altitude, feet*
20,000	12	16,665
	–10	18,600
	–30	20,500
	–50	22,530
30,000	–20	27,730
	–40	29,575
	–60	31,520
35,000	–30	32,755
	–50	34,595
	–70	36,500
40,000	–30	37,700
	–50	39,500
	–70	41,500

The Role of Moisture in Flight

Except for its nuisance effect on the mental complacency of the pilot, atmospheric moisture has a negligible role in the physiology of flight. Temperature and pressure are the major physical variables that affect the welfare of the pilot, as a rule. However, there are two moisture phenomena of the air that are well worth mentioning because of their general interest.

FOGGING AND FROSTING OF WINDOWS.—The first is fogging and frosting of the windows. On the ascent this can be avoided by proper ventilation of the airplane, but on descent from high altitudes the cold interior metal surface may become covered with a heavy dew. If the re-ascent is made, this dew may freeze on the interior windows of the airplane and cause serious inconvenience.

VAPOR TRAILS.—The second phenomenon is that of vapor trails. As yet there is no clear-cut explanation nor are the conditions for their appearance clearly known. Vapor trails are cloud formations, which usually occur at the exhaust of the engines and do not form on the wing tips or ailerons. They appear when the airplane is between 25,000 and 35,000 feet under clear cloudless conditions when the outside temperature is

near −18 degrees C. When they begin to form, a permanent cloud is left behind the airplane, thus producing tactically a dangerous situation, if the airplane is flying over enemy territory. Vapor trails can be avoided by the pilot's going either to lower or higher altitude levels.

A plausible explanation of vapor trails is in order, although it is likely in the end not to be the correct one. For all cloud effects there must be present small condensation nuclei on which formation may take place. These nuclei usually are smoke particles, ions or some product of combustion. When air is "nuclei-free" and cold, it is possible for moisture to exist in a supersaturated state, which can be normalized only by the presence of condensation nuclei themselves. When vapor trails form, it is likely that the ambient air is in a supersaturated state. The condensation nuclei, inherent in the exhaust gases of the engines, immediately precipitate a cloud on reaching the supersaturated air and thus form a cloud-like trail which marks the course of the airplane in flight.

The aforementioned vapor trails should not be confused with a small thin, stationary cloud sometimes observed on the leading edge or wing tip while an airplane is proceeding at low altitudes and when temperatures are close to freezing. This type of condensation re-evaporates rapidly and leaves no trail.

CHAPTER III

THE PHYSIOLOGY OF RESPIRATION AND CIRCULATION IN RELATION TO FLYING AT HIGH ALTITUDES

The Respiratory System

INTRODUCTION.—Respiration is commonly called "breathing." However, it may be more explicitly defined as "the exchange of gases between an organism and its environment." In the case of all animal organisms, respiration consists principally of the exchange of oxygen and carbon dioxide. Oxygen is taken into the body and utilized to burn the food from which energy is derived to operate all the mechanism necessary to keep the body alive and active. The oxidized gaseous product of this combustion, principally carbon dioxide, is then eliminated, completing the process known as "respiration." This exchange of gases takes place continuously throughout the life span of an organism, from conception to death.

From a physiological point of view, respiration in the body of man may be considered under two divisions, namely:

INTERNAL RESPIRATION.—This has to do with the exchange of gases between the body tissue cells and the blood as the blood passes through the minute capillary blood vessels which permeate every tissue in the body.

EXTERNAL RESPIRATION.—This has to do with the exchange of gases between the blood in the lung capillaries and the external atmospheric environment as represented by air in the air sacs of the lungs. This presentation of the subject of respiration is concerned chiefly with the principles of *external* respiration.

The processes operating in the exchanges of gases between blood and tissues and between blood and lungs do not differ qualitatively in a normal individual. In one case, diffusion is into the blood from the lungs, and in the other case it takes place in the reverse direction; hence, out of the blood and into the cells.

STRUCTURE OF THE LUNGS.—Since the exchange of gases in external respiration takes place in the lungs, knowledge of the anatomy of lungs and of the physical and chemical principles involved in the exchange of gases therein is desirable. No detailed description of the gross anatomy of the lungs will be given; in figure 3 some idea of the relationship of the lungs to the other organs of the chest is given. The structure of the final division of the lungs, namely the alveoli or air sacs, is illustrated in figure 4. These air sacs form the functionally important part of the respiratory tract, because it is within them that the exchange of gases between the body and the environment takes place. The tracheobronchial tree of a rabbit is seen in figure 5*a*, and in figure 5*b* a cluster of alveoli from the lung of a dog is seen. Each alveolus, of which there are several million in the average human lung, is approximately 1/25 of an inch in diameter. The total surface area of all the alveoli in the

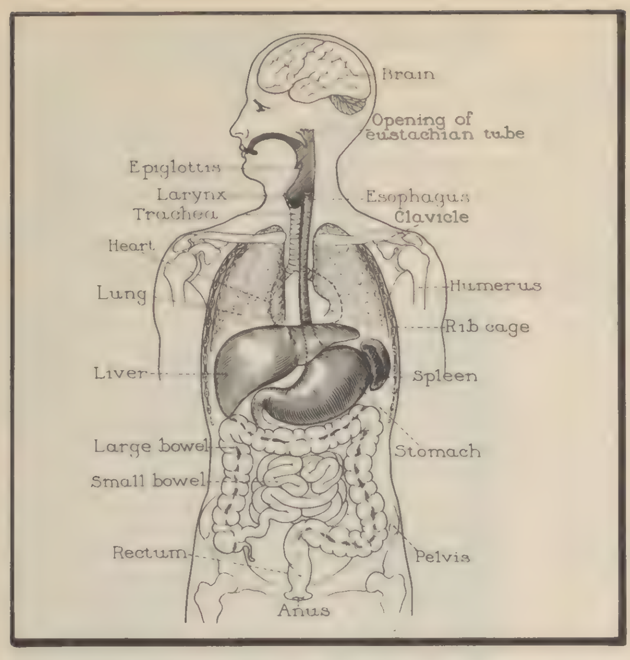


Figure 3.—The respiratory tract of man, showing the air passages and position of the lungs within the thoracic cavity.

human lung has been estimated to be between 700 and 800 square feet, which is forty to fifty times the surface of the skin of the body. The walls of these alveoli are moist and extremely thin, being only about 1/50,000 of an inch in thickness. Each alveolus is surrounded by a network of capillary blood vessels through which blood flows at all times. It is the gaseous exchange between the blood in these capillaries and the air in the alveoli that is of utmost importance to the body. Although this exchange of gases must take place across two membranes, namely the alveolar wall and the capillary wall, these membranes are so thin that they offer no appreciable resistance to the transfer of dissolved gases. Actually, the blood remains in the lung capillaries for only about one or two seconds, and in this short space of time the necessary exchange of gases is accomplished.

MECHANICS OF BREATHING.—The flow of gases to and from the alveoli is a mechanical process. The lungs lie completely enclosed within the cavity of the chest. The sides of the chest cavity are rendered rather rigid by the ribs. The diaphragm, a partition composed of muscle, lies below. The chest cavity is constructed in such a manner that its total volume can be increased or decreased by muscular activity which raises or lowers the ribs or by contraction and relaxation of the diaphragm. Since the chest is a closed cavity with only one opening to the outside, namely the trachea, it follows that changes in its size will ventilate the air spaces in the lungs (fig. 6*a* and *b*). *Inspiration* is the active phase of this process, and *expiration* is largely a passive phenomenon resulting from relaxations of muscle. The ventilation rate is the total amount of air moved into and out of the lungs within a given period of time.

RESPIRATORY CYCLE.—The average man when at rest will expand the chest cavity at each inspiration to an extent which will draw into the lungs and respiratory passages about 500 ml (about 30 cubic inches) of air. Approximately, this same volume of air is expelled with each expiration. This process is then repeated about twelve to sixteen times a minute in most individuals, although some normal men will breathe as infrequently as four times per minute.

The volume of air inhaled and expelled with each breath is called the "tidal volume." The tidal volume when multiplied by the number of breaths taken per

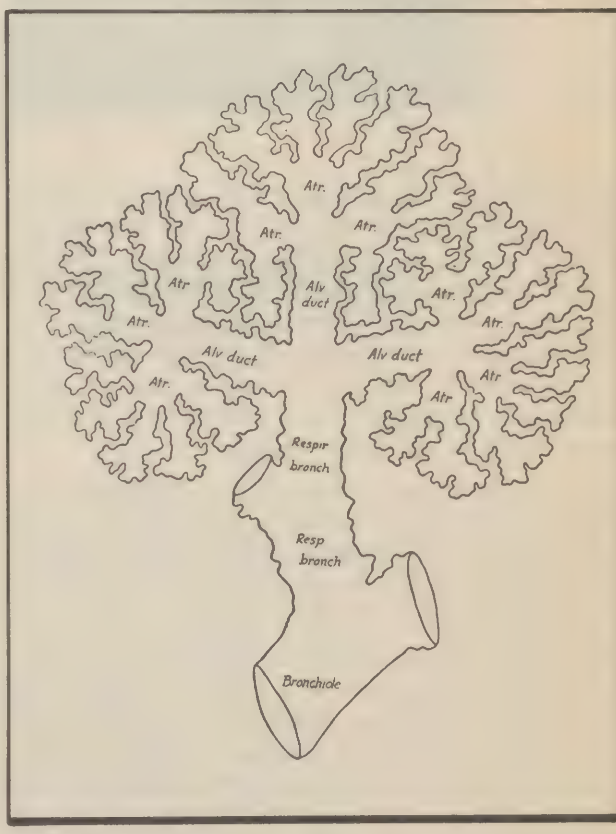


Figure 4.—Arrangement of three lung lobules of cat, showing their respiratory bronchioles, alveolar ducts, atria and air sacs (after Miller, W. S.: The air spaces in the lung of the cat. J. Morphol. 24:459-485 [Dec.] 1913).

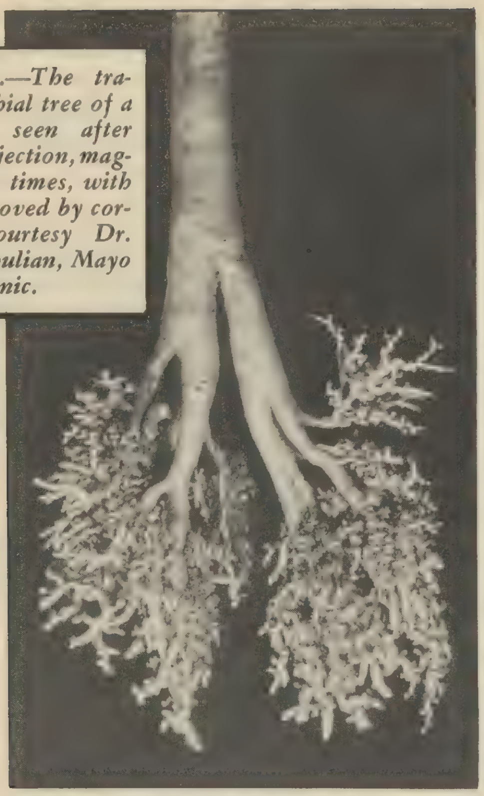


Figure 5a.—The tracheobronchial tree of a rabbit as seen after metallic injection, magnified four times, with tissues removed by corrosion. Courtesy Dr. A. H. Bulbulian, Mayo Clinic.

Figure 5b.—Portion of the lung of a dog after metallic injection. In the central portion is a cluster of alveoli arising from one bronchiole. Courtesy Dr. A. H. Bulbulian, Mayo Clinic.

minute will give the volume of air inhaled (and exhaled) per minute. The volume of air thus breathed per minute is termed the "ventilation rate" and in the average individual at rest amounts to 6 to 8 liters (500 ml x 12 to 16 breaths per minute = 6,000-8,000 ml = 6 to 8 liters per minute). The volume of gases respired by a pilot is about 9 liters per minute. In one test on a flexible machine gunner it was found to be 27 liters per minute while he was firing his gun.

The volume of air which can be exhaled from the lungs after the deepest possible inhalation is termed "vital capacity" and represents the maximal value to which the tidal volume might be increased. These facts are illustrated diagramatically in figure 7.

Of the 500 ml taken into the respiratory system with each inspiration, the last 140 or 150 ml never reaches the alveoli, this being the volume of air necessary to fill the respiratory passages leading from the nose to the alveoli. It is the first air to emerge on exhalation, and, if analyzed, its gaseous composition is found not to have changed appreciably from that of outside air. The remainder of the tidal air mixes with the gases in the alveoli. The composition of alveolar air ordinarily remains very constant at ground level.

COMPOSITION OF RESPIRED AIR.—The exchange of respiratory gases between air in the lungs and blood, and in the opposite direction as blood passes through tissue capillaries, follows those physical laws which govern the behavior of gases in general. A brief space will be devoted to a general account of the properties of respiratory gases.

Atmospheric air on a dry basis and by volume contains 20.93 per cent of oxygen, 79.03 per cent of nitrogen, and 0.04 per cent of carbon dioxide. Included in the nitrogen are small amounts of rare gases which are of no physiologic significance. The relative composition of dry atmospheric air does not vary appreciably with altitudes of up to 70,000 feet. There are no significant variations with latitude.

PERCENTAGE VERSUS PARTIAL PRESSURE.—To express gas quantities by percentage figures means very little when variations in altitudes are involved. The percentile figures given refer only to the relative volume of gases and not to their molecular concentrations. The actual concentrations of any gas can be expressed better in terms of its *partial pressure.* But to understand *partial pressure* we must first understand *total pressure.*

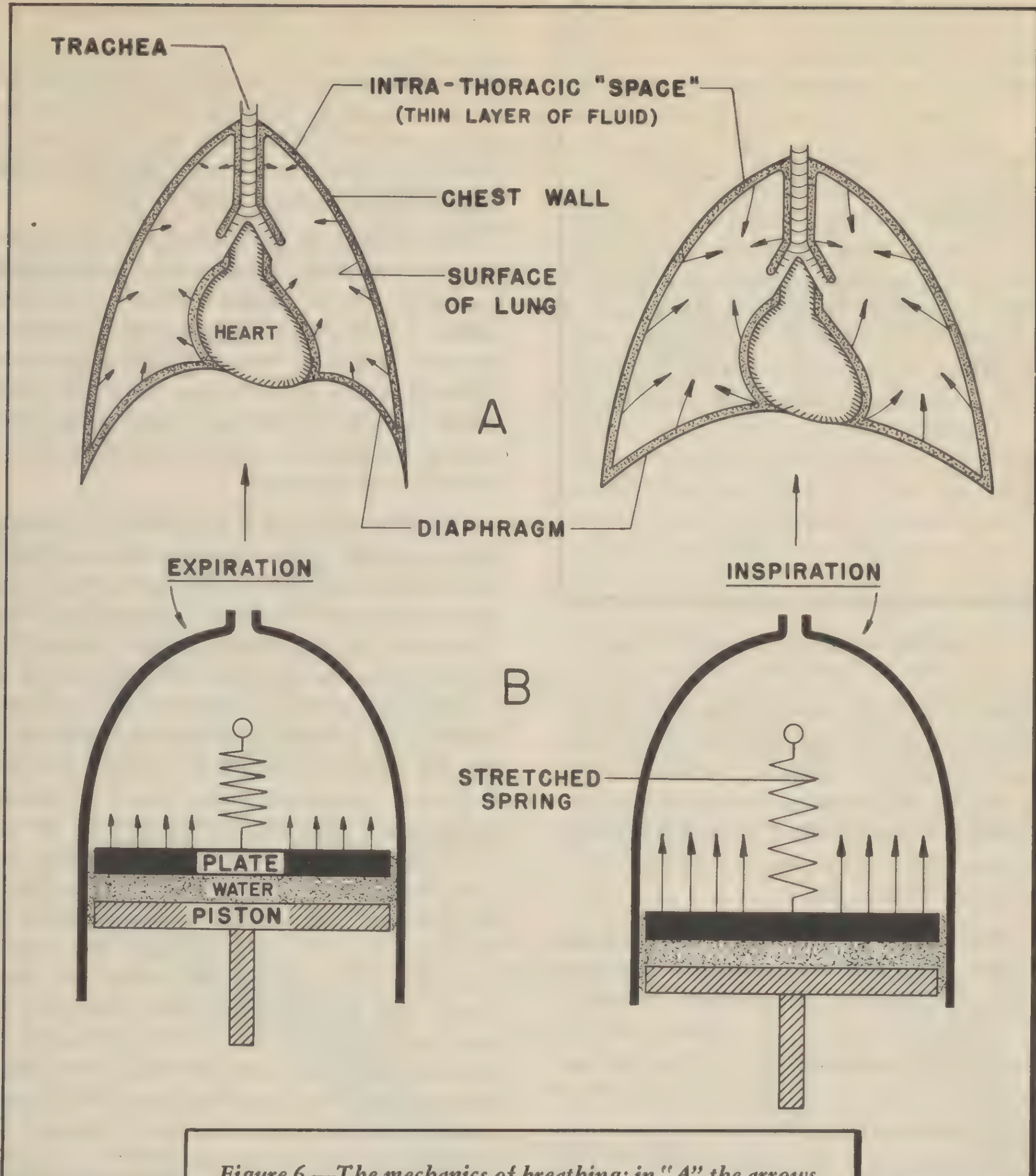


Figure 6.—The mechanics of breathing: in "A" the arrows represent the tendency of the lung surfaces to pull away from the chest wall. The lengths of the arrows represent the degrees of that pull. The intrathoracic space (the space between the tissue of the lungs and the chest wall) is filled with a thin layer of fluid. The lung surfaces remain in contact with this layer of fluid and the lungs expand and contract as if they were a part of the chest wall itself. In "b" is illustrated how INSPIRATION is the active phase of the respiratory cycle, the piston pulling against a spring and drawing in air. The expiratory phase occurs as the result of recoil of the spring when the piston is released. The elasticity of the chest wall makes possible a rapid elastic recoil of the lungs. (Redrawn from Carlson and Johnson: The Machinery of the Body.)

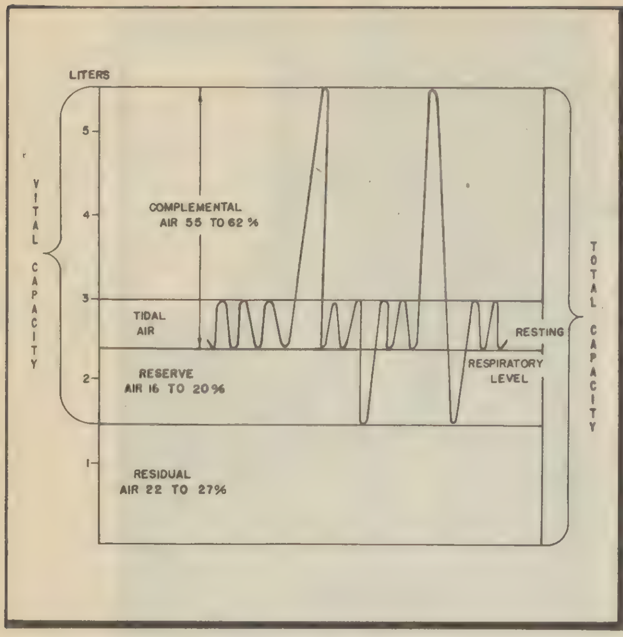


Figure 7.—Various subdivisions of air in the lungs.

TOTAL PRESSURE.—A quantity of gas when mixed with other gases exerts the same pressure as it would exert were the other gases not present. The *total pressure* of a mixture of gases is, therefore, the sum of the pressures of the individual gases in the mixture. For example, the *total pressure* (barometric pressure) of the atmosphere at sea level is 760 mm. Hg.

PARTIAL PRESSURE.—Assuming that the air is dry, the pressure exerted by oxygen at sea level is, therefore: $\frac{20.93}{100} \times 760 = 159$ mm. Hg. The pressure exerted by nitrogen at sea level is, similarly, $\frac{79}{100} \times 760 = 601$ mm Hg. The figure, 159 mm. Hg. is the *partial pressure* of oxygen; the figure, 601 mm. Hg. is the *partial pressure* of nitrogen. Together these two figures form the total atmospheric pressure of 760 mm. Hg. at sea level. (These figures include a small percentage of carbon dioxide and other rare gases in the atmosphere.)

At an altitude of 18,000 feet the atmospheric pressure is 380 mm. Hg. or one-half the pressure at sea level, which means that half the total mass of the atmosphere is below 18,000 feet. Now, the percentage of oxygen in the atmosphere at an altitude of 18,000 feet is still 20.93, but since the partial pressure of oxygen at this altitude is half the partial pressure of oxygen at sea level, it can be seen that at such an altitude the amount of oxygen which is available to the body is greatly reduced. The partial pressure of oxygen at this altitude is: $\frac{20.93}{100} \times 380 = 79.5$ mm. Hg. again, a half of the partial pressure of oxygen at sea level. At 27,000 feet the atmospheric pressure is a third its sea level value; at 33,400 feet it is a fourth its sea level value and at 38,500 feet it is a fifth its sea level value.

The quantity of gas which goes into solution (temperature remaining constant) is proportional to the partial pressure of the gas concerned. For example, if a person is breathing atmospheric air, approximately half as much oxygen or nitrogen will be physically dissolved in blood plasma at 18,000 feet as will be physically dissolved at sea level. This has a bearing on both the problems of oxygen want at high altitudes and on problems related to aeroembolism.

THE RESPIRATORY GASES.—The atmospheric air that is breathed contains variable amounts of water vapor, but as soon as air is drawn through the nasal passages and into the trachea, it becomes saturated with water vapor. Therefore, the approximate partial pressures of the respiratory gases as they enter the lungs at sea level are: oxygen, 149; nitrogen, 564; water vapor, 47; and carbon dioxide, 0.3 millimeters of mercury. When air is drawn into the lungs it mixes with air already in the lungs which is lower in oxygen and higher in carbon dioxide than the inspired air. Therefore, when samples of expired air are analyzed it is found that they contain less oxygen and more carbon dioxide than does inspired air. The nitrogen and water vapor remain the same. Naturally, the expired air does not give us a true picture of the conditions that exist in the alveoli (air sacs) of the lungs, since it is a mixture of air from both the alveoli and the outside air. The *partial pressure* of oxygen in the alveoli is what is significant for the body, for it is this pressure that determines how much oxygen can be taken up by the blood. In table 3 is shown the partial pressures of the gases in the alveoli at sea level and at various altitudes. Note that the partial pressure of oxygen in the alveoli at 34,000 feet, when a man is breathing pure oxygen, is the same as that at sea level when he is breathing air. At an altitude of 40,000 feet the partial pressure of oxygen is greatly reduced. At altitudes of more than 40,000 feet the partial pressure of oxygen decreases rapidly and is beyond the limit which would permit of enough uptake of oxygen by the blood to maintain the body in a safe physiologic state.

THE EXCHANGE OF GASES IN THE LUNGS.—The question of how gases are acquired by the blood has been the subject of much study by physiologists

TABLE 3

THE COMPOSITION AND PARTIAL PRESSURES OF ALVEOLAR AIR AT SEA LEVEL AND VARIOUS ALTITUDES

Alveolar gases	*Breathing Air at sea level*	*Breathing Pure Oxygen at, feet* 30,000	34,000	40,000
		Millimeters of mercury		
Oxygen	100	138	100	57
Carbon dioxide	40	40	40	38
Nitrogen	573	0	0	0
Water vapor	47	47	47	47
Total pressure	760	225	187	142

for a long time. Present-day knowledge indicates that the exchange of gases between lungs and the blood takes place by means of physical diffusion and that it follows the fundamental physical laws governing gas. Gases diffuse from regions of higher partial pressure to those of lower partial pressure. This is proved by experiments in which samples of arterial blood are analyzed for gas content and compared with the composition of gas in the lungs. This is easily done at ground level, but becomes very difficult at higher altitudes. Such has been accomplished, however, and in figure 8 is shown the percentile saturation of blood with oxygen at altitudes of up to 44,000 feet while subjects were breathing pure oxygen.

CONTROL OF BREATHING.—Normal breathing is essentially an involuntary act. However, it is to a certain extent under voluntary control. Regulation of breathing movements is accomplished at lower altitudes by responses of the nervous system to *carbon dioxide* rather than to the concentration of *oxygen* in the blood. The origin of nerve impulses affecting frequency and depth of respirations is in the upper region of the spinal cord. This region is called the *respiratory center*. When the content of carbon dioxide in the blood is increased, as it is during exercise, the respiratory center is stimulated and nerve impulses are sent out that increase the rate and depth of respiration. At altitudes of more than 12,000 feet without oxygen, and at altitudes of more than 35,000 feet with oxygen, a reduction of the amount of oxygen in the blood begins. This reduction in the oxygen tension will cause an increase in the rate and depth of breathing by stimulating the carotid body, which is an organ formed in the carotid artery, where it branches in the neck. The carotid artery carries blood to the head.

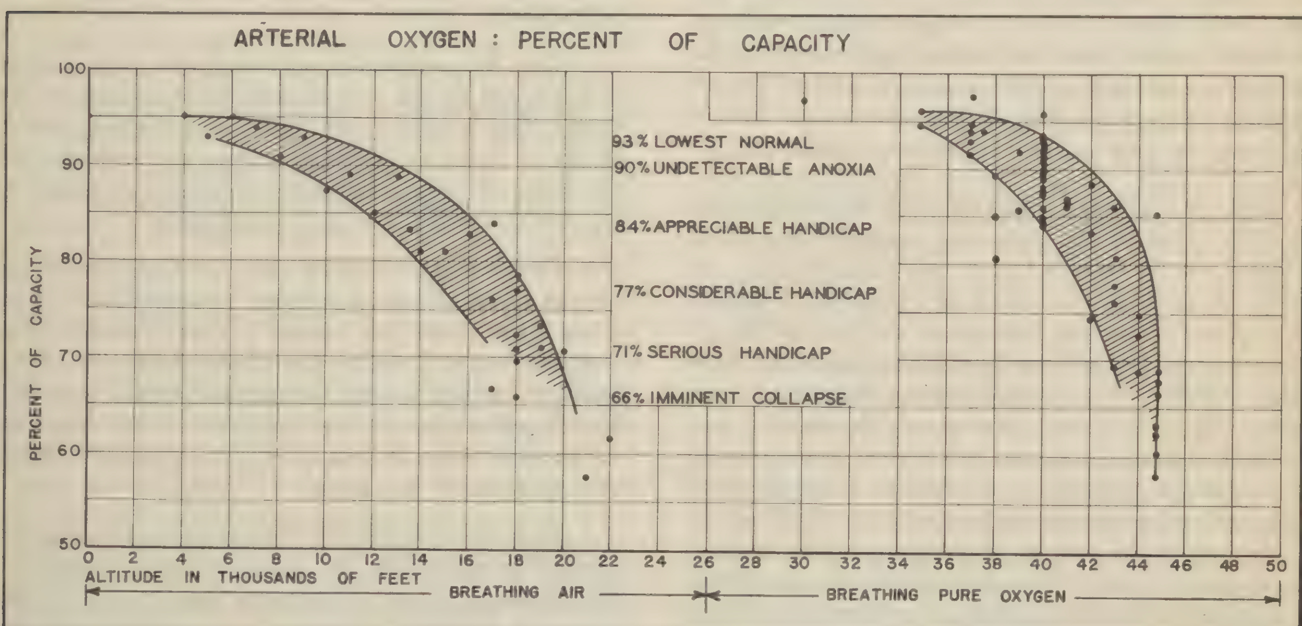


Figure 8.—Percentile saturation of arterial blood at altitudes of up to 44,000 feet, with subjects breathing pure oxygen. The curves on the left show the range of performance among persons breathing air. Curves on the right show the range of performance among persons breathing pure oxygen.

Under ordinary circumstances and at ground level, this relative insensitivity of the respiratory control mechanism to anoxia (insufficiency of oxygen) imposes no undue hardship on the person affected, because as the need for oxygen in the body cells increases (as for example, during exercise), the output of carbon dioxide by the cells likewise increases. The amount of carbon dioxide carried by the blood is increased, the respiratory control mechanism is stimulated, and the ventilation rate is increased to accomplish elimination of the carbon dioxide. The increased rate of ventilation increases the amount of oxygen which is brought into the alveoli (air sacs) of the lungs and which is thus made available for absorption by the blood, but it is only because of the close parallel between the *rate of production* of carbon dioxide and the *need for oxygen* by the body tissues that the oxygen requirement is so well met at ground level.

ANOXIA.—At higher altitudes the situation is very different. At such altitudes a given ventilation rate will result in the elimination of approximately the same amount of carbon dioxide as at ground level; but, due to the decreased amount of oxygen in a given volume of air as the atmosphere becomes rarefied (less dense), the same ventilation rate will not make the same amount of oxygen available for absorption by the blood. Thus, an aviator at altitudes between 10,000 and 15,000 feet may suffer from a lack of oxygen without any appreciable increase in his ventilation rate and without the slightest awareness of his anoxic condition (insufficiency of oxygen.) This is a subject which will be discussed in greater detail in ensuing chapters.

THE TRANSPORT SYSTEM FOR RESPIRATORY GASES.—One of the important problems of modern warfare is the transportation of materiel from the bases of supply to the bases of operations. Likewise, one of the important activities in the human body is the transportation of gases from the lungs to cells of the body, which cells, in a sense, are the "front lines" and where the real "action" takes place. The blood is part of the transportation system and is itself properly called a "tissue." It functions very efficiently in transporting gases and other constituents to the active tissues of the body and in like manner it transports all the broken-down material away from the cells. Blood tissue is like a ship that carries a full cargo from points of embarkation to points of debarkation and returns fully laden with another cargo.

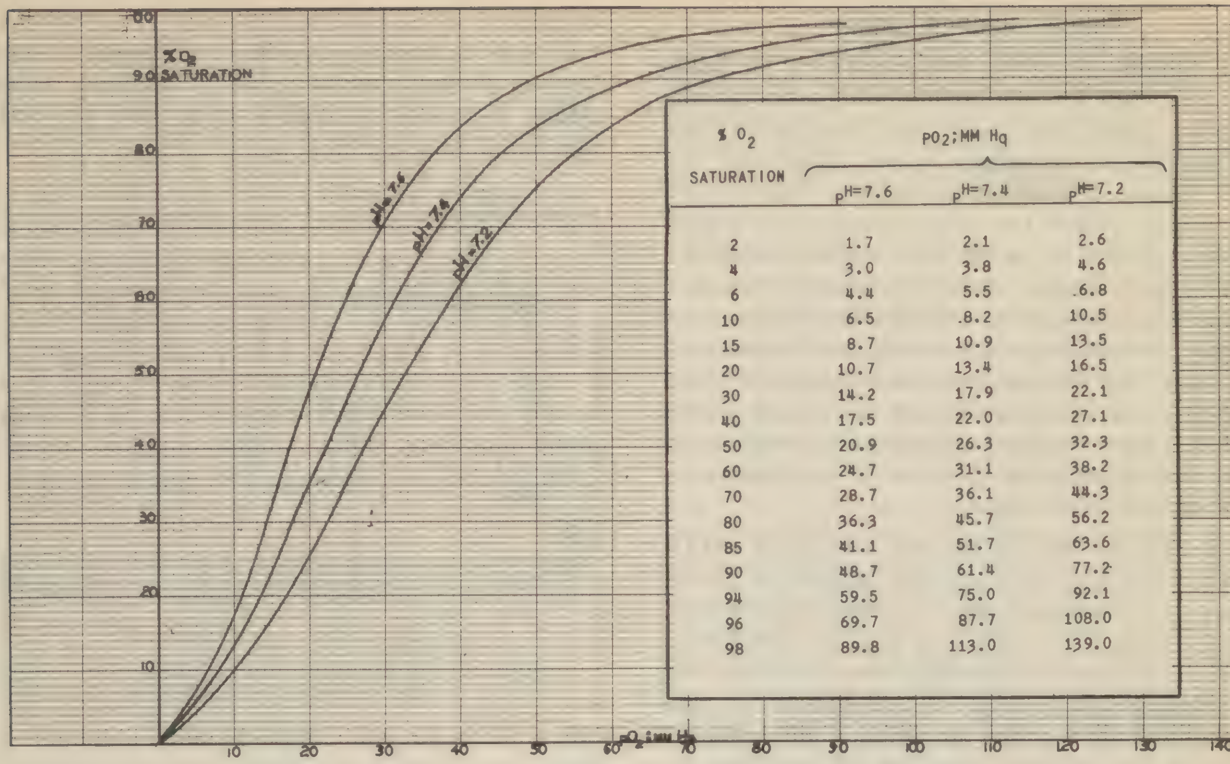
The transportation of respiratory gases is accomplished mainly by the combination of these gases with special blood constituents. Far greater quantities of these gases are carried in the blood than could be present in the simple solutions in the plasma. (Plasma is the fluid portion of the blood before clotting occurs. It does not include red blood cells or white blood cells.) At sea level pressures, only about 0.2 cc of oxygen and about 0.3 cc of carbon dioxide could be carried in 100 cc of blood plasma in simple solution. Actually, we find that 100 cc of blood contains about 18 to 20 cc of oxygen and about 40 to 50 cc of carbon dioxide. Note that this is about 100 times the amount of oxygen and about 130 times the amount of carbon dioxide that would be carried by simple solution. This ability of the blood to carry such a large load of oxygen is due to a red pigment contained in the red blood cells, called "hemoglobin." It is hemoglobin which gives the blood its color, but hemoglobin also combines easily with oxygen. Since, in general, the chief function of the red blood cells is to carry oxygen from the lungs to the body tissues, it can be seen how important hemoglobin is to the red blood cells. Carbon dioxide is carried largely in the form of bicarbonate ions both in the plasma and in the red blood cells.

THE TRANSPORTATION OF OXYGEN.—Oxygen combines reversibly with hemoglobin in a unique manner to form oxyhemoglobin. In figure 9 curves of dissociation of oxyhemoglobin may be studied. It can be observed:

1. That the combination of hemoglobin with oxygen is influenced by the *partial pressure* of oxygen in the surrounding medium. This has a direct effect on the ability of blood to transport oxygen to the tissues of the body at various altitudes at which variation in the *partial pressure* of oxygen would occur.

2. That hemoglobin has a relatively high affinity for oxygen at certain *partial pressures* of oxygen and a relatively lower affinity for oxygen at lower pressures. The S-shaped curves indicate this phenomenon. Thus, the blood has a high *loading* capacity for oxygen as it (the blood) passes through the capillaries of the lungs and an increased *unloading* capacity when it passes through the capillaries of the tissues.

3. That the hydrogen ion concentration, conveniently denoted as pH, affects the oxygen carrying capacity of hemoglobin. (As the pH becomes greater than 7.0 the degree of *alkalinity* is greater; as the pH becomes less than 7.0 the degree of *acidity* is increased.) Variations in hydrogen ion concentration are due largely to variations in the content of carbon dioxide, and this in turn is by respiratory regulation. When one breathes deeply,



% O_2 SATURATION	PO_2; MM Hg pH=7.6	pH=7.4	pH=7.2
2	1.7	2.1	2.6
4	3.0	3.8	4.6
6	4.4	5.5	6.8
10	6.5	8.2	10.5
15	8.7	10.9	13.5
20	10.7	13.4	16.5
30	14.2	17.9	22.1
40	17.5	22.0	27.1
50	20.9	26.3	32.3
60	24.7	31.1	38.2
70	28.7	36.1	44.3
80	36.3	45.7	56.2
85	41.1	51.7	63.6
90	48.7	61.4	77.2
94	59.5	75.0	92.1
96	69.7	87.7	108.0
98	89.8	113.0	139.0

Figure 9.—Oxygen dissociation curves for human blood.

the *partial pressure* of carbon dioxide in the blood decreases and the blood becomes more alkaline; that is, the pH increases to more than 7.0. It will be observed on inspection of the first curve in the figure 9 that when the pH has increased to 7.6, the blood is 71 per cent saturated with oxygen at a *partial pressure* of oxygen, pO_2, of 30. On the other hand, when respiration is slowed, the blood may become more acid because of the accumulation of carbon dioxide; that is, the pH declines. At this same *partial pressure* of oxygen of 30 mm. Hg. blood at the normal pH value of 7.4 is 58 per cent saturated, whereas with a pH of 7.2 it is only 46 per cent saturated. Since hemoglobin combined with oxygen is more strongly acid than when it is free from oxygen, it affects the amount of carbon dioxide that can be combined with bases in the blood. Thus, there is a reciprocal relationship between the transportation of oxygen and carbon dioxide. The greater the concentration of oxygen, the less carbon dioxide is the blood capable of carrying; and the greater the concentration of carbon dioxide, the less oxygen is the blood capable of transporting. It follows, then, that since carbon dioxide leaves the blood by way of the capillaries of the lungs, arterial blood can carry a larger amount of oxygen than can venous blood, and that, when arterial blood arrives at the tissues where carbon dioxide is produced and transferred to the blood, a relatively greater amount of oxygen must leave the blood for utilization in the tissues. Arterial blood contains, therefore, a relatively larger amount of oxygen, and venous blood a relatively larger amount of carbon dioxide, than would be the case if this reciprocal relationship did not exist. Consequently, hemoglobin plays a very important role in the adjustment of individuals to high altitudes.

4. Since the combination of oxygen and hemoglobin is a loose one and readily reversible, and since oxygen in the tissues is present by virtue of an efficient process of diffusion, it follows that the percentage saturation with oxygen of blood leaving the lungs is a fairly valid criterion of the physiologic state of an individual at various altitudes (figure 8). A reservation must be made here: even after the oxygen is taken up by the lungs, it must be carried to the tissues. This service is rendered by the circulatory system upon whose efficiency man's well-being depends, particularly in times of stress. A generalized schematic diagram of the mammalian circulation system is seen in figure 10.

The Circulatory System

RESPONSES OF THE CIRCULATORY SYSTEM TO CHANGES IN ALTITUDE.—Responses of the circulatory system are much more complicated than are those of the respiratory system. Heart rate and blood pressure do not increase greatly from ground level up to 10,000 feet while persons are breathing air and up to 38,000 feet while persons are breathing pure oxygen. When an altitude is reached at which the saturation of arterial blood decreases appreciably, an increase in both heart rate and blood pressure occurs. This indicates an increased output of blood by the heart. Emotional factors may have a much greater effect upon heart rate than variations in altitude. In figure 11, for example, the response of the heart in an emotional crisis is illustrated.

THE EFFECT OF EXERCISE AT HIGH ALTITUDES.—This effect depends upon whether or not acclimatization has taken place. In acclimatized individuals mild exercise carried out at high altitudes has no greater effect upon heart rate than it has at sea level, but in nonacclimatized individuals mild exercise at high altitudes produces the same symptoms as will strenuous exercise at low altitudes. Flyers do not ordinarily become acclimatized because they do not live at high altitudes for sufficient time for such adjustments to take place. Since training accomplishes somewhat similar adjustments in the circulatory system as occur during acclimatization, it follows that flyers who engage in some form of physical exercise regularly will better accommodate themselves to high altitudes than will those who lead sedentary lives.

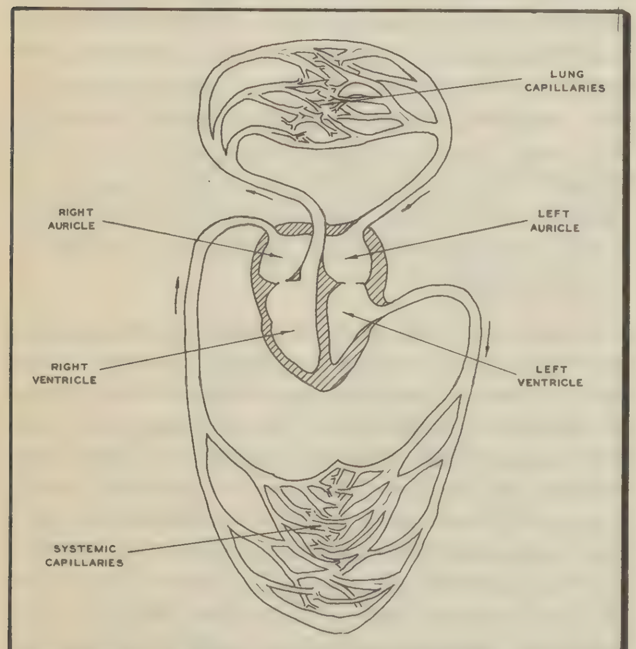


Figure 10.—Generalized schematic diagram of the mammalian circulatory system.

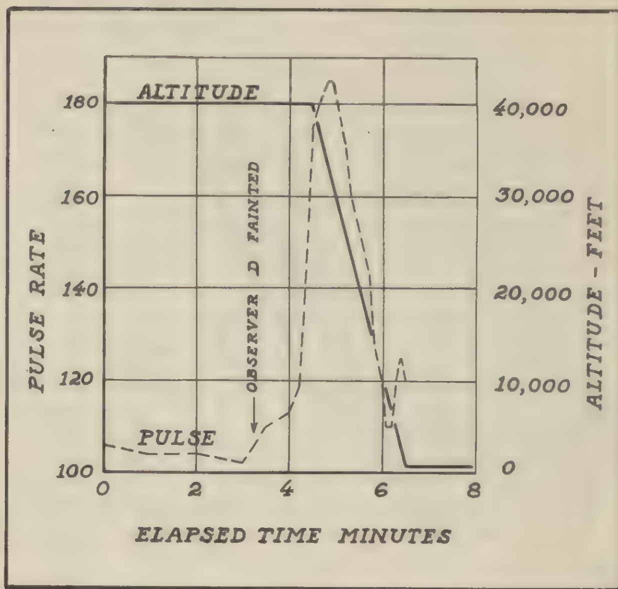


Figure 11.—Record of the heart rate of a subject, C, who was in the altitude chamber at a simulated altitude of 40,000 feet. He was performing moderate exercise when one of his observers, Major D, collapsed. C's heart rate exhibited some increase during the seconds when D was acting queerly. At about the time it became clear to C that D had fainted, C's heart rate increased rapidly to 185. It is presumed that the return to normal began when D exhibited signs of a return to consciousness. Such emotional storms are likely to occur in one member of a crew when another collapses. In such an excited man, judgment would be impaired even though his supply of oxygen was adequate.

CIRCULATORY FAILURE. — One of the greatest hazards associated with flying at high altitudes involves the circulatory system. It occurs because in moments of crisis the output volume of the heart may be reduced. The flyer may faint as the result of some injury or of an unendurable pain caused by aeroembolism. Such a vasomotor shock leads to a decreased volume of venous blood returning to the heart. The minute volume of the heart will become diminished and a small quantity of blood will be pumped to the brain. At altitudes so high that the oxygen saturation of arterial blood is barely above a critical level, fainting or circulatory failure becomes extremely perilous.

Acute and Chronic Effects of Oxygen Want

ACUTE LACK OF OXYGEN.—Meaning of anoxia —The condition induced by an inadequate concentration of oxygen in the air breathed is commonly known as "anoxia," from Greek words meaning "without oxygen." Although by derivation the term "anoxia" means "without oxygen," the common usage of this term implies an intermediate degree of oxygen depletion. The degree of anoxia depends upon the reduction of the *partial pressure* of oxygen in the alveoli or air sacs below its normal value. What determines the tactical efficiency of a flyer at high altitudes is the amount of oxygen which is available to the cells of his body, particularly to those cells comprising the central nervous system.

FAILURE OF CELLS TO CARRY ON THEIR NORMAL PROCESSES OF ENERGY EXCHANGE.—This may be determined by oxygen supply and oxygen supply, in turn, may depend on any one of three conditions or on a combination of them.

1. The first and most familiar of these is a low amount of oxygen in the air breathed. This is the type of anoxia encountered at high altitudes either when the flyer neglects the use of his oxygen oquipment or when his oxygen equipment fails.

2. A second condition also confronted by flyers, particularly in war time, is inability of the blood to transport enough oxygen. This may be related to anemia arising from excessive loss of blood or from carbon monoxide poisoning. In the latter condition, the oxygen-carrying red blood corpuscles temporarily have a lessened capacity as oxygen transporters. Unfortuately, the oxygen-combining pigment of the red blood cells, hemoglobin, has about 200 times greater affinity for carbon monoxide than for oxygen. As a result, even in low concentrations of carbon monoxide, hemoglobin combines with this gas to the partial exclusion of oxygen. This will be discussed further in chapter IV.

3. The quantity of oxygen delivered by the blood to the cells depends not only on the oxygen-combining capacity of the blood but also on the rate of flow of the blood. This is increased in a healthy person exposed to oxygen deficiency, but it may be decreased either as a result of fear, of pain, or of injury, particularly if the injury involves loss of blood.

PHYSIOLOGIC STATES INDUCED BY ANOXIA. —Under ordinary conditions at ground level, the blood is approximately 95 per cent saturated with oxygen. An increased rate of breathing or the breathing of pure oxygen will increase the saturation; in the latter case it raises it to 100 per cent. This small increase in the oxygen in the blood has but little physiologic effect in a healthy person. On the other hand, if saturation decreases to much less than 95 percent, effects begin to show.

The relationship of altitude to the oxygen saturation of arterial blood, subsequently referred to as "arterial saturation," is evident in figure 8, in which the expected arterial saturation at a given altitude, together with a statement of expected symptoms, is shown. It is clearly depicted that 19,000 to 20,000 feet, breathing air, and about 44,800 feet, breathing oxygen, are the highest tolerable altitudes for exposures lasting longer than a very few minutes. Length of exposure is a very important consideration. Most men can tolerate an altitude of 18,000 feet for a half hour without using oxygen, but even though they may be conscious they will be in a befogged state, and collapse almost certainly will ensue eventually. The same men will remain conscious for a few minutes at 25,000 feet, but at such an altitude collapse will occur more rapidly. Consciousness may be lost within a minute at 30,000 feet and within thirty seconds at 35,000 feet. At 35,000 feet death will certainly soon follow loss of consciousness.

Lowering of the arterial saturation from 95 to 85 per cent, if it happens slowly, may not affect the ability of a flyer to do his job. He may himself be unaware of any change until he starts working, as, for example, operating a flexible machine gun, when shortness of breath will be experienced. This range of anoxia, extending down to 85 per cent arterial saturation, can be tolerated for considerable periods (figure 8), but results of psychologic tests show that reduced performance in mental tests occurs or that the carrying out of complicated operations comparable to blind flying is impaired. Frequent errors in judgment may be made. Navigation problems may become increasingly difficult to solve jeopardizing the mission or even the lives of the entire crew.

Whereas an arterial saturation of 85 per cent may have only slight effect in daytime flying, it would be very serious at night because of the effect on night vision. Even the slightest degree of anoxia will greatly reduce the ability to see at night, and it is for this reason that all flyers are ordered to use oxygen at any altitude, from the ground up, on night missions. The problems of night vision are discussed further in chapter IX.

A further lowering of the arterial saturation to about 80 per cent shows greater effects (figure 8), even on the resting person, particularly if the period of exposure

is long. Vision will be somewhat dimmed even in daylight; at night it will be considerably affected. Hand tremor may appear or increase, errors in judgment are frequent and thinking and memory are clouded. Respiration usually will begin to increase. Collapse at this degree of saturation is rare, except in cases of pain or fear, when fainting may result. Exercise with this degree of anoxia becomes increasingly difficult, and the onset of fatigue is rapid. Breathlessness and panting result from exercise.

A saturation of 75 per cent is approaching the danger zone; the handicap is considerable. Even while the person is resting respiration is increased. Exercise brings on deep breathing and the muscles doing the work will be "leaden." Pain in the working muscles may end the work. The same symptoms mentioned above are present, but to a greater degree. Fainting is frequent when pain or fear is involved. Although some people lose much of their reasoning power, not everyone is so seriously affected, and a considerable degree of mental ability may be retained for periods of moderate length. A resolute pilot may marshal reserves of will power and fly his airplane successfully for some minutes.

An arterial saturation of 70 per cent is approaching the limit of human tolerance (figure 8). At such a saturation a wide variation is noted in the responses of different persons. If the exposure is not too long, many people can perform moderately difficult tasks, and mental capacity is not critically impaired. However, breakdown is very frequent and again pain or fear may cause the person to collapse.

Arterial saturations ranging down to about 60 per cent are compatible with consciousness in many subjects if the lowering of the saturation has been rapid and if the low value is not prolonged. Figure 8 shows the expected arterial saturation of oxygen at 44,800 feet. Eight experienced subjects have spent from fifteen to forty-four minutes at this altitude (simulated) in the low pressure chamber and arterial punctures (puncture of an artery to remove a specimen of blood for analysis of its degree of saturation with oxygen) have been performed, the results of the analyses of the blood forming the points noted on the graph (figure 8) for that altitude. Only one of eight subjects who took part in these tests was near collapse at any time during the experiments. The subject whose arterial saturation was 62 per cent was able to perform arterial puncture on another subject after having had his own blood drawn. With excitable or inexperienced subjects it is doubtful if this could have been done.

When the arterial saturation decreases to about 60 per cent, coordination is lost, and writing may either lose all legibility or a fair degree of legibility may be retained, with a loss of intelligibility. This represents a brief transitory period between useful consciousness and total collapse.

Recovery from anoxia.—Recovery is rapid when sufficient oxygen is restored. An individual on the threshold of unconsciousness may, within fifteen seconds, regain his full faculties when abundance of oxygen is furnished him. Some have the impression that a person in such a state should resume the use of oxygen cautiously. There is no convincing evidence supporting such an idea. Experience shows that if a person who is very anoxic breathes deeply of oxygen he may occasionally experience a flash of dizzinesss, but this immediately passes and complete restoration of normal function follows.

Headache.—Headache is a common complaint of persons after a severe prolonged period of anoxia. Some people appear to be very susceptible to this type of headache. The headache appears to be general, but is particularly acute in the frontal region. The best cure is sleep, although when headache is severe, the administration of oxygen is advisable. This headache has been explained as being a result of an edema or "water-logging" of the tissues, particularly the nervous tissues, as a result of an increased capillary permeability caused by the anoxia. Although anoxia has been both feared and respected for a long time, permanent disability arising from it is rare. Permanent damage to the brain has been observed in severe carbon monoxide poisoning, but there are no authentic records of cases in which anoxia has caused permanent impairment in flyers. A man either recovers his full faculties or he dies.

Ceiling.—Individual variability in the ability to withstand anoxia is great; it accounts for variation in "ceiling." This may be related to the person's respiratory adjustment; that is, to the stimulation his respiratory center receives from anoxia. Although any healthy flyer breathes more deeply when he becomes very anoxic, his response may be, at a given altitude, an increase of 50 per cent or one of 200 per cent. For example, in the performed tests at a simulated altitude of 44,800 feet in the low pressure chamber, the only man who complained of a subsequent headache had experienced the smallest increase in breathing.

Increased breathing in anoxia.—The immediate gain resulting from deeper breathing that occurs involuntarily in acute exposure to oxygen deficiency is twofold.

Extra carbon dioxide is removed, and this increases the oxygen in the lungs and at the same time makes the blood more alkaline and so favors the uptake of oxygen by the hemoglobin of the blood. At such extreme altitudes as 40,000 feet, where pure oxygen must be breathed, the barometric pressure, which is the same in the lungs as it is outside, equals the sum of the *partial pressures* exerted by water vapor, carbon dioxide, and oxygen. The water vapor pressure is constant, corresponding to a saturated state at 37 degrees C. Consequently, lowering of the *partial pressure* of carbon dioxide, such as occurs in deep breathing, will increase the *partial pressure* of oxygen in the lungs by an equal amount.

Hazards of deep breathing.—Although man's normal response to anoxia is to increase the pulmonary ventilation rate, some individuals do this excessively, so that tetanic convulsions may occur. This is rarely seen in healthy flyers, however. An additional complication arises in deep breathing at high altitudes when the present constant-flow oxygen equipment is used. Atmospheric air will be drawn in through the sponge rubber discs, thus diluting the oxygen and producing anoxia.

The relationship of shock to anoxia.—This is likewise important. By "shock" is meant a state of partial circulatory collapse in which many of the small blood vessels become dilated. Pooling of the blood results, particularly in the abdomen. In this state, more than the usual number of capillaries are open and filled with blood; it has been aptly said that in shock a man bleeds into his capillaries. The causes of this vasomotor collapse are varied and include such things as fear, pain, and loss of blood. Anoxia itself, in some individuals, may produce vasomotor collapse, even in its early stages. When this happens, a vicious cycle of events occurs, leading to general collapse.

The supply of oxygen to the brain and central nervous system.—This is dependent upon both adequate circulation of blood to the brain and the concentration of oxygen in the blood flowing to the brain. If the content of oxygen in the blood supplied to the brain is normal but the flow of blood is decreased, the oxygen supply to that organ will be diminished. This is the state in which fainting occurs at ground level. When the flyer's equipment fails to supply him with the proper amount of oxygen at altitude, his brain is the first organ to suffer, as has been pointed out before. Superimposed on this condition is a circulatory handicap arising from fear, pain, or loss of blood may produce collapse when either state in itself could have been withstood.

Apprehension.—It is well known that inexperienced and emotionally unstable persons collapse more frequently at intermediate altitudes, when the arterial saturation is still not greatly reduced from normal, than do normal persons. This may be associated with a state of mild shock resulting from apprehension. Education and experience tend to combat this.

Chronic Anoxia.—The reactions spoken of until now in this section all pertain to the subject who is anoxic for only a short time; that is, a matter of a few hours at the most. The person who remains for days, weeks, or months in a state of deprivation of oxygen has very different experiences. Such a person undergoes some organic changes, the whole process of which we speak of as "acclimatization." This is seen in persons who go to mountain communities to reside for some time. Headache, nausea and general debility often accompany the process of acclimatization. Men have become acclimatized to altitudes of as much as 17,500 feet. In Chile there is one community of about 100 sulfur miners and their families who live at this altitude.

Two reports concerning subjects who passed through the stages of anoxia described herein are included to demonstrate the reactions in sequence. The stories follow:

Reports of Cases

CASE 1.—Oxygen failure in the altitude chamber at Wright Field.—On December 23, 1941, a group of experienced subjects were being tested for resistance to aeroembolism at an altitude of 40,000 feet. One man had already been "brought down." By the time the chamber was brought back to altitude, two others were experiencing pain; Lieutenant TRN and Private RCF. They delayed descent for some minutes, thinking the pains might not become worse. Finally, Private F decided to come out. It was his impression that Lieutenant N also was coming out. As soon as he entered the lock, he changed to a mask with a short tube in order to pass the mask with an extension tube back to the lieutenant. After having made this change, he discovered that Lieutenant N was not coming out, and he proceeded to close and lock the door. His short tube was attached to an oxygen cylinder of the heavy welding type on the far side of the lock. The observer at a view port could see that in the process of locking the door Private F was exerting enough tension on the line to rock the cylinder dangerously. The operation of closing the door required about thirty seconds, and Private F then came back beside the cylinder, directly in front of the observation

port. He signaled to "go down," and the observer passed on the signal to the chamber operator (see frontispiece). Almost at once, probably within fifteen seconds, tremor was noted in the arm with which Private F was holding his mask. The operator was ordered to open the descent valve full on.

The observer was able to see all that happened during the next few seconds, since Private F was facing the view port. He had failed to fasten the strap on his oxygen mask, but was holding it in his right hand. The first sign of impending collapse was tremor in his right hand, resulting in loosening the mask. This passed rapidly into convulsive twitching in the right arm, and simultaneously an expression of anxiety appeared on his face. The twitching increased, the mask had by now fallen from his face, and then convulsions appeared to become more general. For perhaps five seconds, he sagged to a half-reclining position on the floor; then his head fell back against the edge of the steel door, almost out of view. The pressure was lowered rapidly to what it would be at an altitude of 10,000 feet. Shortly after, the subject sat erect, and as soon as he gave the signal, pressure was brought down to what it would be at ground level.

Private F was examined immediately. Aside from a superficial cut in the scalp, he appeared to have suffered no ill effects. After an hour's rest in bed, he went about his duties.

Inspection of the equipment afterward showed that Private F had failed to turn his oxygen fully on; the gage of the A-8 regulator stood at about 25,000 feet. Furthermore, the oxygen cylinder had rocked back and was leaning against the wall of the chamber. The accident might have had serious consequences if the cylinder had tipped in the other direction and fallen on the soldier.

His collapse can be attributed in part to his failure to turn the oxygen supply fully on, but there was the added handicap of pain from aeroembolism. Standing erect by a person in pain may result in fainting, even at ground level. When a person stands erect at an altitude of 40,000 feet with an inadequate oxygen flow, it is doubly hazardous. In the case of Private F judgment and co-ordination both failed. When the mask fell from his face, collapse was complete.

As a result of this experience, rules governing "lock descent" were established, to insure that no such accident will occur again.

CASE 2.—Oxygen failure on a high-altitude flight by an Army flyer.—"In the winter of 1936 to 1937, while a pilot attached to the 27th Pursuit Squadron, First Pursuit Group at Selfridge Field, Michigan, it was my privilege to help conduct performance tests of the latest thing in pursuit aircraft—a full squadron of brand new Consolidated PB-2's. This ship was powered by a geared Curtiss Conqueror with one of the first electrically controllable pitch propellers and equipped with a turbo-supercharger for high altitude operation. The oxygen system was of the type using liquid oxygen, now abandoned in favor of gaseous oxygen. The turbo made the PB-2 the ultimate, at that time, in performance at altitude.

"One morning I took off as one of a flight of six, with the intention of reaching the absolute ceiling of the ship, and, of course, making notes of instrument readings, fuel consumption, and other items of engine performance.

"Starting to take oxygen at 8,000 feet, I stuck the 'pipe stem' in my mouth—no oxygen masks in those days—and turned the regulator to correspond to the altitude. All went well as we steadily climbed in formation.

"After the 24,000 foot level was reached, the other boys began to drop out and return to the field—some with spark plug trouble causing excessive vibration and loss of power, others with overheating engines. Finally at 32,000, only the flight leader and myself remained.

"The climb continued with all well until 35,000, when the other ship dropped below me, but continued on course. I made notes of everything I could think of, but remember only the temperature—about −62°F and mighty uncomfortable.

"About this time, I recall that the sky—long since devoid of clouds or any type of moisture—seemed to darken perceptibly from a deep blue to almost purple. Also, I didn't seem to be able to think of anything in particular, and finally couldn't remember what I was up there for or what I was supposed to be doing. I looked at the instrument board several times, and with a good deal of squinting with one eye managed finally to locate the altimeter and noted the altitude as 36,200 feet. Looking back down at the other ship, which I had kept in sight, I was astounded to see *two* ships there, in perfect formation. This seemed odd, but my head by this time was too slow to wonder much about it.

"Suddenly, I noticed that the great void of the sky was almost black, and I couldn't see the instrument board, much less read any instruments. It filtered through my brain that all was not well.

"On an impulse from I don't know where, I throttled back the engine and pushed over into a shallow dive, and that was the last I knew for what seemed like days.

"Finally, consciousness began to return, and the earth began to swim vaguely before my eyes, and then near-normal vision returned. I noticed I was diving almost vertically at somewhere near 400 miles an hour, with the Packard Proving Grounds directly ahead in the gun sights. I also noticed the altimeter. It read 4,000 feet and was unwinding fast. Easing the stick back slowly, I pulled out at an uncomfortably low altitude, and circled while I collected my wits.

"Finally, I returned to the field and landed, turned in my notes to the engineering officer, and made no comment on my performance after reaching the 36,200 feet the notes indicated. Somehow, I thought, I pulled a boner, and it might be a good idea to keep it to myself while I did a little more studying on the use of oxygen equipment and altitude flying in general.

"We had studied the oxygen system of the ship; I knew enough to keep the regulator opened to the corresponding altitude at which I was flying, but no one had told me how it felt or what the symptoms of simple "oxygen lack" were, and I'd failed to recognize it until too late—or almost too late. The whole trouble had been the low temperature—it had caused the slight amount of moisture in the oxygen to freeze in the oxygen line or regulator, gradually cutting off my oxygen supply."

With improved regulators and oxygen masks, and knowledge of the reactions of a human being at high altitudes now available to pilots, an experience like the preceding is most unlikely. It is as important to learn the proper use of the oxygen equipment as it is to learn the proper handling of the guns or a bomb sight.

CHAPTER IV

NOXIOUS GASES IN AIRCRAFT

INTRODUCTION.—The presence of noxious gases in aircraft compartments has been almost completely eliminated by modern construction methods. Nevertheless, in view of the extreme toxicity of carbon monoxide at high altitudes, it is considered necessary to discuss this potential danger.

Carbon monoxide normally occurs in the exhaust fumes of aircraft engines as a result of the incomplete combustion of carbonaceous material. The amount present varies considerably, depending on the octane rating of the fuel, the air-fuel ratio, the throttle setting and the altitude, and extends over a range of from 1 to 7 percent, with an average of 2.8 percent.

The Amount and Mode of Entrance of Exhaust Gas Reaching Aircraft Compartments

This amount also varies considerably, since it becomes diluted with atmospheric air before it enters the cockpit. One of the most important factors in determining the concentration of exhaust gas in the cockpit is the question of whether or not the engine is situated directly in front of the fuselage, such as is usually seen in single motored or trimotored aircraft. Little difficulty has been experienced with two-motored or four-motored aircraft. When an engine is placed immediately in front of the personnel compartment, the amount of exhaust gas entering it depends largely on the manifold system. The worst condition is usually encountered in engines with short exhaust stacks. In one type of airplane which had given difficulty for years, it was finally found that the fumes were entering an opening at the extreme rear of the airplane, where the tail wheel emerged. The fumes then traveled forward in the fuselage, causing a dangerous concentration of carbon monoxide about the pilot. Closing of the opening for the tail wheel by means of a boot at once eliminated the difficulty. This experience indicates that the exhaust gases should be discharged at a distance away from the slipstream which immediately surrounds the fuselage. When this is not practicable, care should be exercised to insure that all openings in the fuselage and fire wall are closed. Additional sources of entry of carbon monoxide into aircraft compartments are leaks in cabin heaters which utilize the exhaust gases as a source of heat. Finally, during severe operations under combat conditions, it is considered possible that the effects of enemy gunfire, not necessarily terminating flight missions, may open up exhaust collector rings and holes in the fuselage and fire wall, causing dangerous concentrations of carbon monoxide in the cockpit.

Mechanism of Carbon Monoxide Poisoning

To understand why concentrations of carbon monoxide which are of little importance at ground level become dangerous at high altitudes, it will be necessary to give a short resume of the mechanics of carbon monoxide poisoning.

The deleterious effects of carbon monoxide on the human organism are the results of a dual action of this gas on the blood, an action which thereby produces a state of anoxia, the nature and effects of which have been discussed in chapter III. In the first place, carbon monoxide combines with the hemoglobin in the blood in a manner similar to that of oxygen, but, as stated in chapter III, the affinity of hemoglobin for carbon monoxide is more than 200 times as great as its affinity for oxygen, so that in the competition for a place in the hemoglobin molecule, the odds are more than 200 to 1 in favor of carbon monoxide, to the exclusion of oxygen. This in itself would be serious enough, but the carbon monoxide already present in the arterial blood acts to increase further the anoxia by preventing the liberation from the blood in the tissues of that amount of oxygen that does succeed in getting in. Hence, the extraordinary intensity of the anoxia caused by combination of carbon monoxide with a given proportion of hemoglobin is explained. Therefore, our concern about carbon monoxide poisoning at high altitudes is fully justified when one realizes that even a small loss in the oxygen carrying power of blood already impoverished of this gas due to low barometric pressures is likely to produce the dangerous symptoms of acute lack of oxygen.

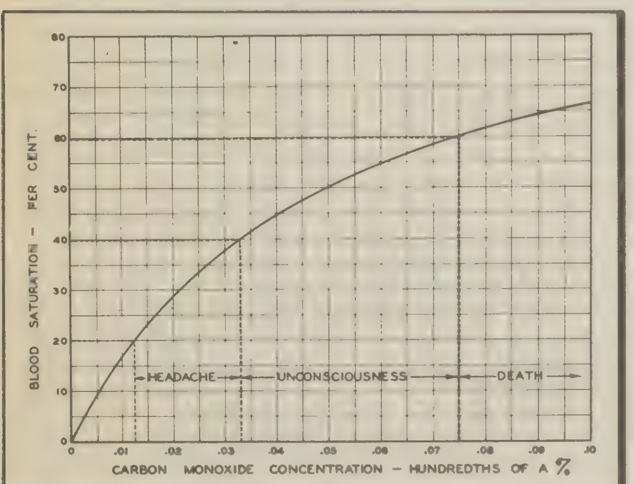


Figure 12.—Saturation of the blood with carbon monoxide and resulting symptoms produced by various concentrations of carbon monoxide in the inspired air.

The blood saturation attainable with various concentrations of carbon monoxide in the inspired air and the resultant ultimate effects are shown in figure 12. It will be noted that headache is one of the first symptoms to appear, so that all instances of violent headache should be carefully watched.

Symptoms of Carbon Monoxide Poisoning

The symptoms generally are known and vary with the carbon monoxide content of the blood, as shown in table 4. In table 5 is shown the effect of various concentrations of carbon monoxide in the inspired air at ground level. It will be noted that it requires 0.04 percent to produce the first symptoms. The symptoms of carbon monoxide poisoning which occur during aircraft flight are governed by three factors: (1) the concentration of carbon monoxide, (2) the duration of exposure, and (3) the altitude. An increase in any or all of these factors will cause an increase in severity of the symptoms produced. In figure 13 are shown the effects of carbon monoxide on arterial saturation at various altitudes. Assuming that the dangerous effects of oxygen want become manifest at an arterial hemoglobin saturation of 80 percent, these curves show that, with no carbon monoxide in the air, this point is reached at 14,000 feet (fig. 13). A similar condition, with 0.005 percent carbon monoxide and 0.01 percent carbon monoxide occurs at 11,600 and 7,000 feet, respectively (fig. 13); thus, as little as 0.005 percent carbon monoxide in effect lowers the altitude tolerance by 2,400 feet, whereas 0.01 percent carbon monoxide in effect reduces the altitude tolerance to half what it would be if only pure air, and no carbon monoxide, were present.

Prevention of Ingress of Carbon Monoxide

In aviation the only logical method of dealing with this problem is to eliminate the carbon monoxide from the cabins and cockpits of aircraft. The onset of carbon monoxide poisoning is so insidious and its effects are so disastrous that preventive measures are the only ones to be relied on. Although it is desirable that no carbon monoxide at all be present in aircraft, in single-engine airplanes this is often difficult to accomplish, and frequently there are traces of the gas present. In this situation it is necessary to establish the allowable concentration of gas which is harmless and which can be measured by practical methods. The maximal permissible concentration in personnel compartments of Army Air Forces aircraft has been established as being 0.005 percent.

TABLE 4

SYMPTOMS WHICH DEVELOP AT VARIOUS CONCENTRATIONS OF CARBON MONOXIDE IN THE BLOOD

Carbon monoxide, percent in blood	*Symptoms*
0-10	None
10-20	Tightness across forehead, possibly slight headache, dilatation of cutaneous blood vessels.
20-30	Headache, throbbing in temples.
30-40	Severe headache, weakness, dizziness, dimness of vision, nausea and vomiting, and collapse.
40-50	Same as previous, with increased pulse rate and respiration, and more possibility of collapse.
50-60	Syncope, increased respiration and pulse, coma with intermittent convulsions, Cheyne-Stokes' type of respiration.
60-70	Coma with intermittent convulsions, depressed heart action—possibly death.
70-80	Weak pulse and slowed respiration, respiratory failure and death.

TABLE 5

DANGEROUS CONCENTRATIONS OF CARBON MONOXIDE

Concentration, percent	*Effect*
0.01, or 1 part in 10,000	No symptoms for 2 hours
0.04, or 4 parts in 10,000	No symptoms for 1 hour
0.06 to 0.07, or 6 to 7 parts in 10,000	Headache and unpleasant symptoms in 1 hour
0.10 to 0.12, or 10 to 12 parts in 10,000	Dangerous for 1 hour
0.35 or 35 parts in 10,000	Fatal in less than 1 hour

Dangerous concentrations of carbon monoxide in aircraft compartments are indicated by:

1. Subjective symptoms, such as throbbing headache, nausea, dizziness or dimming of vision.

2. Odor of exhaust gases.

3. Sounding of a warning signal.

Required action is as follows:

1. Open all cockpit hoods or windows and attempt to eliminate any odor of exhaust fumes by ventilation.

2. Attach oxygen masks and breathe pure oxygen until the symptoms disappear.

3. Descend to lower altitudes as soon as possible.

4. Turn off exhaust type heaters if such are in use.

Effects of Breathing Pure Oxygen

In connection with the breathing of pure oxygen, the question is sometimes raised concerning the harmful effects of this procedure. Oxygen can produce irritation of the lungs if it is breathed for a sufficiently long period at high *partial pressures.* However, since such concentrations do not occur during air travel, it can be said that no harmful symptoms can result from breathing pure oxygen.

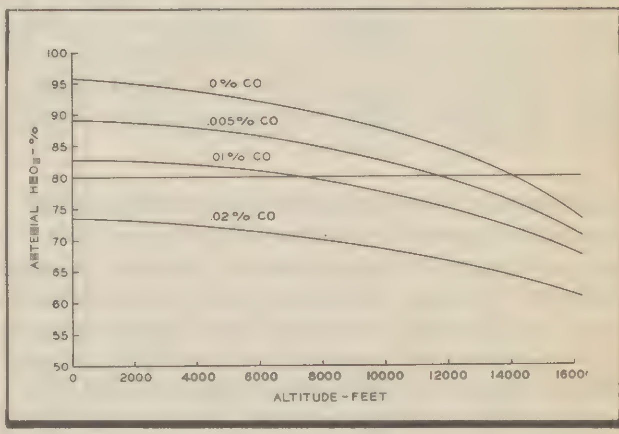


Figure 13.—The effects of carbon monoxide on hemoglobin in arterial blood at various altitudes.

CHAPTER V

EFFECTS OF PRESSURE CHANGES ON THE HUMAN BODY

Aeroembolism (decompression sickness, bends)

DESCRIPTION.—Aeroembolism, known also as "decompression sickness," "bends" and "aeroemphysema," is a condition produced by exposures to low atmospheric pressure (high altitude), and is characterized by the formation of bubbles (consisting of nitrogen, oxygen, carbon dioxide and water vapor) in the tissues, blood and other fluids of the body. Its causative factors are fundamentally the same as in the case of "bends" in caisson workers or deep-sea divers.

The formation of gas bubbles within the human body is exactly similar to the release of bubbles in a bottle of charged water or beer when the cap is removed. In the manufacture of charged water, carbon dioxide is forced into the bottle, under pressure, at the time of filling and, therefore, it goes into solution. When the cap is removed the gas comes out of solution because of the lower pressure of the outside air. As the cap is replaced, pressure is built up until the gas above and that dissolved in the solution are in equilibrium, at which time bubbling ceases. If a container of tap water is taken to high altitudes, gas bubbles like those in bottles of charged water will start to form at approximately 18,000 feet, and are very evident before an altitude of 30,000 feet is reached.

The water, fat and other tissues of the body contain dissolved nitrogen. The amount dissolved depends on the partial pressure of nitrogen in the air. This, in turn, depends on the altitude. If the altitude is changed, a new equilibrium is established. If the change is rapid, there is a lag in the attainment of equilibrium, leaving the body temporarily supersaturated with nitrogen. Thus, in rapid ascents to high altitudes in an airplane, the amount of dissolved nitrogen in the body is in excess of that which can be held in solution. The excess in the blood may be eliminated, through the lungs, and while this is going on the nitrogen in tissues bathed by the blood is finding its way into the capillaries and is carried by way of the blood stream to the lungs, where it is eliminated. When the ascent is rapid and to altitudes of 30,000 feet or more, the nitrogen gas will tend to come out of solution and form bubbles, not only in the blood, but in other tissues as well. Those tissues which have the highest fat content are the most favorable sites for bubble formation, since fat per unit of mass will dissolve five or six times more nitrogen than will blood. Normally, from approximately 1 to 1.5 liters of gaseous nitrogen is dissolved in the body.

As stated above, in addition to appearing in the blood, bubbles may appear in other tissues of the body, the most common locations being the joints and fatty tissues. The symptoms vary in nature and severity, depending primarily on the location and the size of the bubbles that are formed. Experimental evidence indicates that five factors probably are concerned in the production of symptoms. They are (1) rate of ascent, (2) the altitude attained, (3) the time the person remains at the altitude, (4) individual susceptibility and (5) environmental temperature. In general, the more rapid the rate of ascent, the sooner the symptoms occur. At altitudes of less than 30,000 feet (226 mm Hg; that is, less than a third of sea level atmospheric pressure) very few symptoms occur, regardless of the rate of climb, except in the case of unusually susceptible individuals. Above this altitude, symptoms may occur at low rates of climb with varying degrees of intensity and at various times after altitude has been reached. There is considerable variation in individual susceptibility, and a few individuals can go to 40,000 feet and remain there for an hour without experiencing symptoms. The symptoms of aeroembolism ordinarily do not develop immediately but, on the other hand, seldom occur after four hours. Aeroembolism is believed to develop more rapidly when personnel are cold.

SYMPTOMS.—The symptoms of aeroembolism follow in the order of their severity.

Pain.—Pain in and about the joints may be mild at the onset, but often becomes deep, gnawing and boring in character, and may become so severe that it is intolerable. It can even result in loss of muscular power of the part involved; if it is allowed to continue it may result in collapse. The pain may diffuse from the joint region over the arm or leg as a whole, or over the entire area of a long bone. The larger joints, such as those of the knee and shoulder, are most frequently affected. Other joints commonly involved are the small joints of the hands, wrists and ankles. A wrist joint at ground level is seen in figure 14*a*, and a collection of gas in the wrist joint is shown in figure 14*b*. In successive exposures, there is a tendency for pain to reappear in the same place, although this is not invariably

the case. Sometimes pain appears at the site of an old injury. Pain may occur in several joints at the same time. Movement and weight-bearing seem to accentuate the pain. Coarse tremors of the fingers are often seen, particularly if there is pain in one of the joints of the affected extremity.

Lung symptoms.—Lung symptoms, commonly referred to as "chokes," probably are caused in part by blocking of the pulmonary vessels by innumerable small bubbles. This may result at first in a burning sensation underneath the breast bone and, as the condition progresses, the pain becomes much more severe, may be stabbing in character, and is markedly accentuated by the person's taking a deep breath. This is sometimes described as similar to the sensation felt in the chest at the completion of a 100-yard dash. Finally, it is necessary to take short breaths in order to avoid distress. There is an almost uncontrollable desire to cough, but the cough is ineffective and is nonproductive. Finally, there is a sensation of suffocation or smoldering, breathing becomes progressively more shallow, and there is cyanosis (bluish discoloration of the skin of the face). Descent is imperative when this condition occurs, and the sooner the better. This condition, as said previously, is known as the "chokes," and if allowed to progress sufficiently far will result in collapse and unconsciousness. Fatigue and weakness, as well as soreness in the chest, may persist for several hours after descent to ground level when "chokes" have occurred at a high altitude.

Various sensations in the skin.—Tingling, itching and cold and warm sensations in the skin possibly are caused by the local occurrence of bubbles or bubbles in the central nervous system involving nerve tracts leading to these areas in the skin. Not infrequently one experiences cold and warm sensations of the eyes and eyelids, as well as occasional irritation, itching and "gritty" sensations. Occasionally, a red rash may appear on the skin and, more rarely, a wheal accompanied by a burning sensation. Bubbles may occur just underneath the skin, causing localized swelling. When there is excess subcutaneous fat (fat located beneath the skin), soreness accompanied by edema (a swelling caused by accumulation of clear, watery fluid beneath the skin) may be present for one or two days after aeroembolism has occurred in this region. It is uncommon for this manifestation of aeroembolism to become critical.

Blurred vision.—Blurring of vision occurs on rare occasions during or after descent. The exact cause of this is not known, but no permanent after effects have been known to occur.

Toothache.—The breathing of 100 percent oxygen has no deleterious effect on the teeth or on dental restorations. However, reduction in barometric pressure, such as occurs in ascent, occasionally results in acute toothache. The pain is generally sharp and stabbing in character and of short duration, but occasionally a dull or aching pain may persist for some time. In most instances, the pain is located in teeth that have deep fillings and recurs in these same teeth on subsequent ascents. A few individuals have experienced pain in teeth that have been recently filled, and over a period of three or four months this pain, which occurs in ascent, decreases in frequency and severity, and finally no longer occurs. When toothache persistently recurs during ascent, a thorough dental examination should be made.

Effects on nerves.—Several other symptoms occur much less frequently. Among these are pains similar to the pains of neuritis (inflammation of a nerve) which occur when individual nerves are involved. Gas bubbles also may be felt occasionally along the sheaths of the tendons. On very rare occasions, temporary partial paralysis of an arm or leg may occur, and when it does, it is almost invariably associated with pain in the affected limb. This is always relieved during descent.

Duration.—The symptoms of aeroembolism ordinarily do not develop immediately at any given altitude, but may be delayed for from ten minutes to as long as four hours. Thereafter, aeroembolism seldom occurs. Symptoms will occur considerably more rapidly at an altitude of 40,000 feet than at one of 30,000 feet. The manner in which pain is produced is not definitely known.

Ordinarily, the pain is progressive in character and when it occurs it never seems to disappear if ascent is made to a higher altitude—usually it becomes more severe. However, mild degrees of pain may disappear after a few minutes or an hour.

FREQUENCY OF OCCURRENCE OF AEROEMBOLISM.—A single "flight" in the low-pressure chamber is inadequate for reliable high-altitude classification of Air Force personnel, since they might not experience trouble in the first run, but might do so on subsequent runs. Inasmuch as a certain group of flyers will be expected to operate aircraft at 35,000 feet or more, and since the disabling of one member of a combat crew might result in the loss of an airplane or failure of a mission, it becomes necessary to determine the ability of all flyers to tolerate high altitude.

Recently a group of 200 flyers, within a period of five days, made a total of 584 consecutive ascents to

Figure 14a—A wrist joint as seen by the X-rays at ground level.

Figure 14b—Air in a wrist joint at an altitude of 35,000 feet. (The air bubble shows as a black area at the end of the ulna.)

35,000 feet in a low-pressure chamber at a rate of ascent of 1000 feet per minute, and remained there for three hours. During these experiments eighty-seven descents were necessary for the following reasons: seventy-five cases of joint pains, seven cases of "chokes," three cases of abdominal pains due to gas, and one case each of ear distress and hyperventilation (abnormally prolonged and deep breathing). Eighty-six percent of the descents was the result of joint pains, 8 percent was due to "chokes," and 3.5 percent was due to gas pains. Individual susceptibility to aeroembolism is unpredictable without several simulated flights in low-pressure chambers to high altitude. Even then, the results are not absolutely certain. In some individuals symptoms invariably develop above a critical level, whereas others are remarkably immune. Evidence indicates that age, weight and the general state of health play a part. The older and the more overweight an individual is, the more susceptible he is to "bends."

RELIEF OF SYMPTOMS.—Once symptoms develop to a severe degree, immediate relief is imperative and such relief can be obtained only by descent to low altitudes as rapidly as possible (called "recompression"). Most symptoms usually disappear at an altitude of approximately 25,000 feet, although chest symptoms may persist for several hours after a return to ground level. Fatigue is sometimes complained of for several hours after descent, even after ascents in which pain has not been experienced. Permanent injury never has been authentically reported. If collapse and unconsciousness result from aeroembolism, an attempt should be made to place the affected flyer in the recumbent position with the legs elevated, and oxygen should be administered by the continuous flow system (that is, the emergency supply should be turned on to be certain that an adequate amount of oxygen is being obtained) and, if breathing has ceased, artificial respiration should be carried out. Descent should be accomplished as rapidly as possible.

PREVENTION.—The most practical method for reducing the incidence of aeroembolism is to remove nitrogen from the body by breathing pure oxygen immediately before ascent and continuing to breathe pure oxygen from the ground up. Breathing pure oxygen removes nitrogen from the body by reducing the *partial pressure* of nitrogen in the lungs to zero, thereby causing the nitrogen in the body to flow into the lungs and to be expelled in the exhaled breath (figure 15). It is not necessary, however, to eliminate all the nitrogen from the body in order to gain protection from aeroembolism. Experiments have shown that the longer the period of breathing oxygen, the more protection may be expected. It was found in one set of experiments that breathing oxygen while at rest for forty-five minutes before ascent protected all of a group of fifty cadets from disabling symptoms of aeroembolism for three hours at a simulated altitude of 38,000 feet (School of Aviation Medicine, Randolph

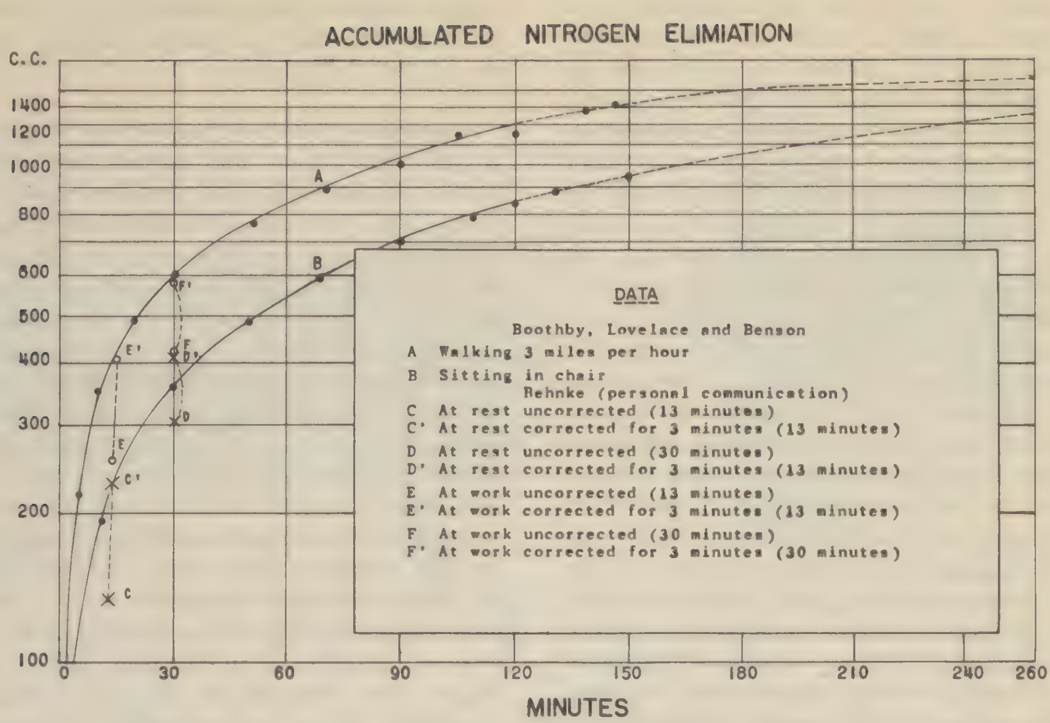


Figure 15—Rate at which nitrogen is eliminated from the body while pure oxygen is breathed. It should be noted that in curve A, in which the subject is exercising, about one-half the nitrogen in the body is eliminated during the first thirty minutes.

Field, Texas). Until now it has been recommended that exercise be carried out while breathing oxygen on the ground before take-off. The experiments above may indicate that exercise is not necessary.

Physical activity at altitudes above 30,000 feet increases one's susceptibility to bends and chokes and should therefore be limited to that which is essential.

A Technical Order covering the subject of denitrogenation is in preparation.

The Effects of Explosive Decompression

Pressure cabin aircraft have the following advantages: (1) they give flyers the ability to go to high altitudes without the supplemental use of oxygen and in the present type of aircraft, if oxygen is used, they give the flyer the ability to exceed altitudes of 40,000 feet; (2) they tend to prevent aeroembolism and gaseous distention, since the body is not exposed to the effects of extremely low barometric pressure; and (3) they permit controlled ventilation and heating. A pressure cabin is especially advantageous when flights are to be carried out over long periods at high altitudes, when any oxygen mask would become uncomfortable and the amount of oxygen carried would have to be large and the containers bulky and heavy.

Among the disadvantages of pressurized aircraft cabins are: (1) increased weight and bulk arising from the necessity for a structural design which will withstand pressure, (2) need for maintenance of additional equipment, and (3) the danger of explosive decompression.

From the standpoint of flyers, the chief hazard to be considered in connection with pressurized cabin aircraft is the possibility of explosive decompression. In case of damage by high caliber shells or explosive shells to the cabin of such aircraft, there might be an almost instantaneous loss of pressure, at which time the cabin would be filled with air at the barometric pressure existing at that particular altitude. The harmful effects of explosive decompression are due to the decreased barometric pressure to which the personnel are exposed, which may result in aeroembolism and will result in acute oxygen want, considerable expansion of the gas in the stomach and intestines, as well as possible injury to the ears.

If the pressure in the cabin were maintained at a level equivalent to 8,000 or 10,000 feet while the airplane was operating at an altitude of 40,000 feet, the decrease in barometric pressure to which personnel would be suddenly exposed would be much greater than if the cabin pressure were being maintained at 25,000 feet while the aircraft was flying at an altitude of 40,000 feet. Of course, in the latter case, flyers would be wearing their oxygen masks, which would be an additional safeguard, since the higher the aircraft is operating, the more serious is the loss of oxygen supply and the more rapid is the onset of anoxia. For example, in some experiments on human beings in low-pressure chambers, it was found that the mean period of useful consciousness when the use of oxygen was discontinued was forty-three seconds at 30,000 feet, twenty-five seconds at 35,000 feet, and fourteen seconds at 40,000 feet. Thus, only a very short interval of time would be allowed for adjustment of an oxygen inhalator if explosive decompression occurred, and it is for this reason that oxygen equipment must be immediately available for flight personnel at all crew stations in pressurized aircraft. The results of studies carried out in low-pressure chambers on the effects of explosive decompression on animals and humans indicate that the greatest potential hazards to personnel are anoxia and aeroembolism. The danger of aeroembolism can be greatly reduced and possibly eliminated by a rapid descent to lower altitudes. For this reason, it has been recommended that pressure cabin controls permit manual adjustment in flight of the pressure to be maintained in the cabin, so that the cabin altitude can be increased from 8,000 to 25,000 feet upon the airplane's entering the combat zone. Even if this procedure is followed, immediate descent to a lower altitude is recommended in the event of loss of pressure, and oxygen in adequate amounts must be available for immediate use.

Effect of Pressure Changes on the Ear

The ear functions both as an organ of hearing and as one of the organs regulating equilibrium. Good hearing is essential to the proper use of aircraft radio and intercommunication systems, and to the detection of abnormal engine sounds.

During flight the ear is affected by changes of barometric pressure in ascent and descent, to a lesser extent by vibration and by noises, principally from the propeller and the engine exhaust, as well as from the slip stream, the radio and vibrating structures within the aircraft. In order to protect the ears during flight as much as possible, the radio should never be tuned to a higher volume than is necessary, and, if aircraft noises are excessive, absorbent cotton plugs can be worn in the external auditory canal.

Anatomically, the ear (figure 16*a*) is composed of: (1) the external ear and auditory canal which terminates at the eardrum, a thin membrane about 0.004 inch in thickness; (2) the middle ear, which is located within the temporal bone of the skull, consisting of a small air space behind the eardrum which communicates with the back of the nasal passages by the eustachian tube; and (3) the internal ear, which has to do with both hearing and equilibrium, and which contains the cochlea, vestibule and semicircular canals. The external and middle ear conduct the air waves that produce the sensation of sound. Within the middle ear are three very small bones which form a chain between the drum and inner ear and conduct vibrations of the drum to the inner ear. The eustachian tube, which connects the cavity of the middle ear to the atmospheric air, is a short slit-like tube which normally remains closed and which extends from the middle ear to the back wall of the throat (figure 16*b*). Through this tube air in the middle ear can escape or can be replenished, thus averting discomfort by constantly providing for the equalization of pressure between the air enclosed within the cavity of the middle ear and that in the surrounding atmosphere.

As the barometric pressure is reduced during ascent to high altitude, the expanding air in the middle ear passes out intermittently to the back portions of the nasal passages through the eustachian tube. As the pressure in the middle ear increases, the eardrum first bulges outward until an excess pressure of approximately 15 mm Hg is reached, at which time a small bubble of air is automatically forced out through the eustachian tube and the pressure within the ear again becomes equalized with the outside pressure, and the eardrum resumes its normal position. Just before the air is forced out through the eustachian tube, there is a sensation of fullness in the ear, and as the pressure is released, there is often a click in the ear.

During descent in an aircraft, the changes in pressure in the ear do not occur automatically, and much difficulty may be experienced in maintaining equalization of pressure in the middle ear with the pressure of the outside air. This results from the fact that the eustachian tube acts as a flutter valve, allowing air to pass outward easily, but resisting its passage in the opposite direction, as illustrated in figure 16*b*. With an increase in barometric pressure during descent, the pressure on the inside of the middle ear falls below that of

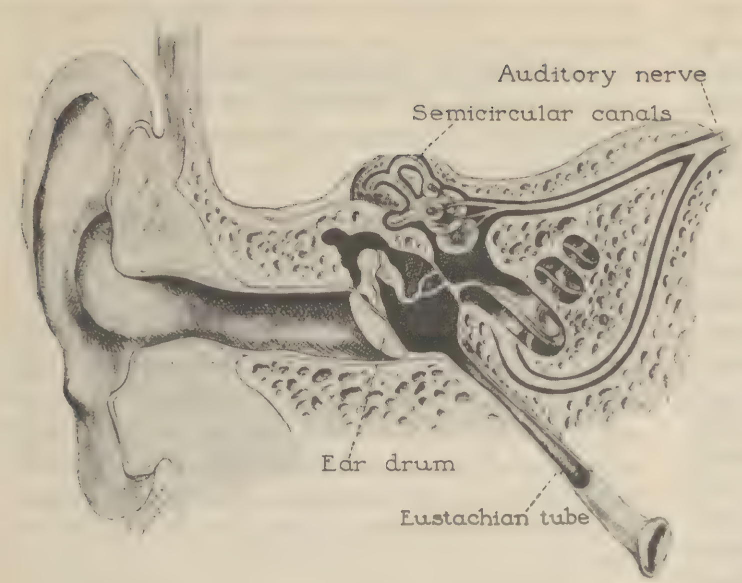


Figure 16a—Schematic representation of the ear.

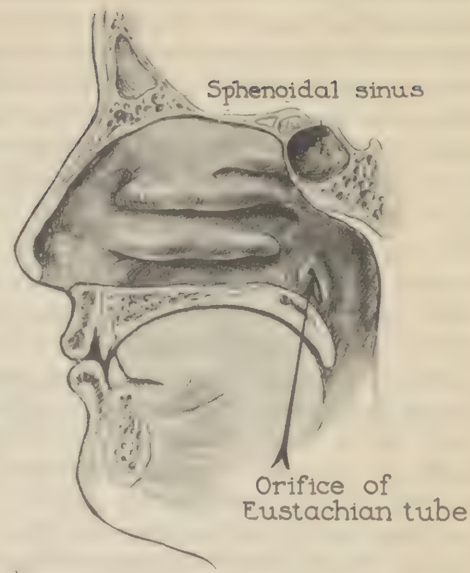


Figure 16b—Orifice of the eustachian tube.

the external air and the eardrum is drawn in toward the middle ear. If the negative pressure in the middle ear is allowed to increase to an appreciable extent, it may be impossible to open up the eustachian tube, which results in increasing pain and eventually may result in rupture of the eardrum. When it is impossible to clear the ears and marked pain supervenes, and if the pain increases with further descent, the only way in which relief can be obtained is ascent to a level at which equalization of the pressure can be accomplished. A slow descent is then recommended. A rapid descent from 30,000 feet to 20,000 feet often will cause no discomfort, whereas a similar descent from 15,000 feet to 5,000 feet will cause great distress because the change in the barometric pressure is much greater in the latter case. In a descent from 18,000 feet to sea level, a difference in pressure of a half an atmosphere may be produced, and the eardrum is therefore forced in with a pressure equal to that of a column of mercury 38 centimeters (15.2 inches) high, which may well produce rupture of the eardrum. If the eardrum is ruptured, it will almost always heal completely in a short time, if it is kept clean and protected from infection, and usually there will be no impairment of hearing. Therefore, special care is necessary in diving at low altitudes.

Normally, there is no difficulty in equalizing pressure during descent, for this can be accomplished by swallowing, yawning or tensing the muscles in the throat at intervals of about 1,000 feet, which causes the pharyngeal muscles to contract and open the eustachian tube. If relief is not obtained by these maneuvers, air should be forced into the middle ear by closing the mouth, pinching the nose shut, and blowing gently, thus forcing air up through the previously closed eustachian tube into the cavity of the middle ear, and consequently again equalizing the pressure. Repeated practice in clearing the ears rapidly improves the rate of descent which can be borne without discomfort, as has been dramatically illustrated in the low-pressure chamber, where experienced personnel can descend routinely at 10,000 to 30,000 feet per minute.

During sleep the normal swallowing reflex does not function, and for this reason it is advisable to awaken sleeping passengers prior to descent, in order to permit them to ventilate the middle ear in the usual manner.

It has been observed that personnel who have been breathing pure oxygen at a high altitude for a considerable period, particularly if oxygen is breathed until ground level is reached, develop ear distress two to six hours after descent. If they are asleep the pain may awaken them. It is believed this is the result of the practically pure oxygen in the middle ear being absorbed and thereby creating a decreased pressure in the middle ear. For this reason it is believed advisable to remove

the oxygen mask at altitudes of less than 15,000 feet when descending from high altitudes in aircraft. In low-pressure chambers where the descent is more rapid and the lungs are filled with pure oxygen, the mask may be removed at altitudes as high as 20,000 feet. A slight degree of anoxia may develop, but under the controlled conditions in the chamber this will not be dangerous. Some controversy exists on this subject and only further experience and experimentation will entirely clarify the matter.

The most common subjective complaint of flyers is discomfort in the ears, caused by inability to ventilate the middle ear voluntarily, which is most frequently caused by the eustachian tube or its opening being swollen shut as the result of inflammation or infection coincidental with a head cold, sore throat, infection of the middle ear, sinusitis or tonsillitis. Forceful opening of the tube in such conditions may result in infected material being carried into the inner ear along with the air, causing disease of the middle ear. Therefore, flyers who have colds and sore throats should not fly unless it is absolutely necessary, and if it is essential, they should endeavor to make slow descents, using a benzedrine inhaler or nasalator (neosynephrin hydrochloride, 0.5 per cent) which shrinks the membranes of the nose and throat and makes equalization of pressure easier.

If equalization of pressure has not taken place on landing, physicians usually can rectify the condition by the use of a spray which shrinks the membranes of the nose, such as neosynephrin hydrochloride, 1 per cent, directed well back into the nasopharynx, or by having the flyer inhale ephedrine or benzedrine compounds. If a pressure chamber is available, reascent can be made to an altitude at which equalization can be accomplished.

When equalization of pressure cannot be accomplished during changes in barometric pressure, a condition occurs which has been named "aero-otitis media."

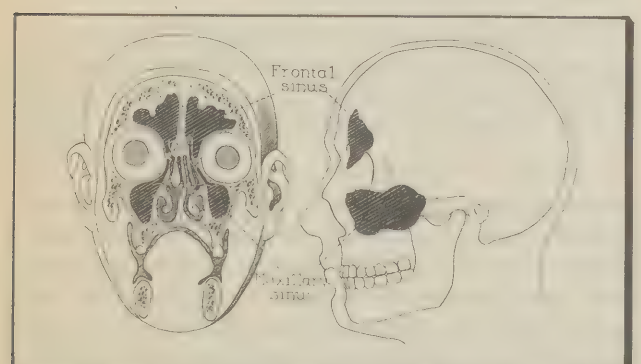


Figure 17—The paranasal sinuses.

This condition can be defined as an "acute or chronic traumatic inflammation of the middle ear caused by a difference of pressure between the air in the tympanic cavity and that of the surrounding atmosphere." It is characterized by congestion, inflammation, discomfort and pain in the middle ear, and may be followed by temporary or permanent impairment of hearing, usually the former.

The Effect of Pressure Changes on the Sinuses

STRUCTURE.—The paranasal sinuses in their normal state (figures 16*b* and 17) present a condition in flight similar to that presented by the middle ear. The sinuses are air-filled, relatively rigid bony cavities lined with mucuous membrane. They communicate with the nose by means of one small opening or occasionally more. Two of these sinuses are situated within the bones of the forehead, one within each cheek bone, and two are located in the bones just back of the root of the nose.

PAIN.—If the openings into the sinuses are normal, air will pass into and out of these cavities without any difficulty at any practical rate of ascent or descent, thus assuring adequate equalization of pressure at all times. If the sinus openings are obstructed, as the result of swelling of their mucous membrane lining brought about by inflammation or an allergic condition such as hay fever, or if the openings are covered by redundant tissue on which viscous secretions are present, ready equalization of pressure becomes impossible. The pressure gradient that is established in change of altitude will produce a differential between the density of the air inside and outside, and result is marked pain. This is the same type of pain that occurs in ordinary sinusitis at ground level, and, in contradistinction to the ears, the sinuses are almost equally affected by ascent and descent.

If the frontal sinuses are involved, the pain extends over the forehead above the bridge of the nose, but if the maxillary sinuses are affected, the pain is on either side of the nose.

Equalization of pressure in the sinuses is best accomplished by yawning, swallowing, or blowing with the nose closed, thus relieving the pain.

TREATMENT.—Treatment of aero-sinusitis should be directed to the obstructed orifices, which can usually be opened by shrinking the nasal mucous membranes with those preparations normally used for this purpose, such as, for instance, the familiar benzedrine inhaler or an 0.5 per cent solution of neosynephrin hydrochloride. If there is persistent recurrence of aero-sinusitis, a search

should be made to determine the presence of possible tumors, polyps, scar tissue or other growths about the sinus openings in the nose.

Effect of Changes in Barometric Pressure On Volume of Gases in the Body

Many of the manifestations of the mechanical effects of low barometric pressure result from the change in the volume of gases within the various cavities of the body. Any free gas within the body tends to increase in volume with the increasing altitude, and to decrease in volume when the atmospheric pressure is increased in descent. This is in accordance with Boyle's law, which states that the volume occupied by a given quantity of gas is inversely proportional to the absolute pressure exerted upon it. In table 6 is shown the comparative volumes of gas at various altitudes.

TABLE 6

COMPARATIVE VOLUMES OF GASES (SATURATED AT 37°C*) INSIDE THE BODY AT VARIOUS ALTITUDES

Barometric pressure, mm Hg	*Barometric pressure, inches*	*Altitude, feet*	*Relative volume of gas saturated with water vapor*
760	29.92	0	1.0
635	25.40	5,000	1.2
523	20.92	10,000	1.5
429	17.16	15,000	1.9
349	13.96	20,000	2.4
282	11.28	25,000	3.0
226	9.04	30,000	4.0
179	7.16	35,000	5.4
141	5.64	40,000	7.6

*Pressure of aqueous vapor at 37°C is 47 mm Hg.

Example of calculation:

$$\frac{760-47}{523-47}=1.5$$

EFFECT OF WATER VAPOR ON THE EXPANSION OF BODY GASES.—Gas enclosed within a body cavity, such as gas within the stomach or intestine, is always under the pressure of the external atmosphere, although this pressure can be modified significantly by the elastic properties of the enclosing organ and by the pressure of the surrounding structures. For simplicity, it is assumed that organs like the intestine are freely expansible. When the pressure of the exterior surface of the body is decreased, the interior pressure must similarly decrease. It must be emphasized that air within the body cavities is saturated with water vapor, because the walls of such cavities are moist with body fluids, and that the pressure of water vapor at 37 degrees C is 47 mm Hg. Therefore, pressure of the gases at sea level would be equivalent to the barometric pressure less that due to the 47 mm of water vapor; consequently, at sea level

$$P=B_1-47=760-47$$

If we now ascend to 40,000 feet, where the barometric pressure is 141 mm Hg, it is obvious that the effect of water vapor will be relatively greater, since

$$P=B_2-47=141-47$$

The expansion of the gases in any body cavity on ascent from sea level to 40,000 feet will be increased in a ration of

$$\frac{B_1-47}{B_2-47}=\frac{760-47}{141-47}=\frac{713}{94}=7.6$$

and not simply as occurs in a balloon filled with dry gas, in accordance with the ratio

$$\frac{B_1}{B_2}=\frac{760}{141}=5.4$$

This shows how much the expansion of gas kept fully saturated with water vapor exceeds the rate at which dry gas expands with decreasing pressure.

Those body cavities which communicate directly with the external atmosphere, such as the sinuses and the middle ear, are capable of equalizing pressure changes, provided their openings are not obstructed. Those changes occur at comparatively low altitudes; for example, 10 cc of air or gas (saturated with water vapor at 37 degrees C) becomes 15 cc of air or gas at an altitude of only 10,000 feet.

GAS IN THE STOMACH AND INTESTINES.—The stomach and the small and large intestines normally contain a variable amount of gas which is always maintained at a pressure approximately equivalent to that of the atmosphere surrounding the body. Considerably more gas is contained in the stomach and large intestine than in the small intestine. The source of this gas is chiefly swallowed atmospheric air and, to a lesser extent, gas formed as the result of digestive processes; that is, fermentation, bacterial decomposition and putrefaction of food which is undergoing digestion.

Gases normally present in the gastro-intestinal tract are oxygen, carbon dioxide, nitrogen, hydrogen, methane and hydrogen sulfide. These occur in varying proportions, although the highest percentage of the gaseous mixture is always nitrogen.

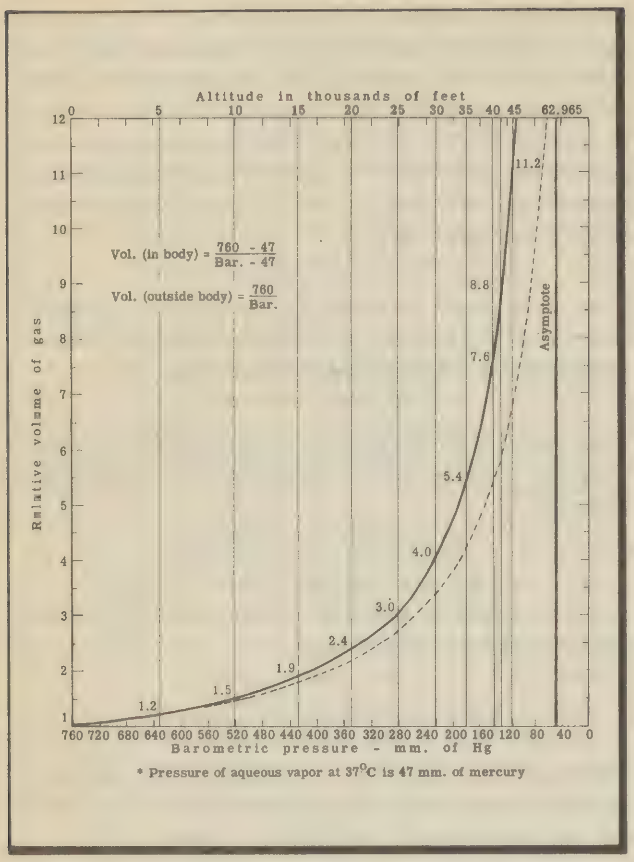


Figure 18—Comparative volumes of gases (saturated at 37°C or 98.6°F) inside the body at various altitudes.

During ascent, the gases in the stomach and intestine expand with altitude as shown in figure 18 and table 6. Ordinarily, relief is obtained by belching and the passing of flatus. If relief were not obtained in this fashion, extreme discomfort would result and, at very high altitudes, there might well be interference with respiration due to elevation of the diaphragm; for example, with the initial volume of 1 liter of gas, the volume of such gas would be 1.5 liters at 10,000 feet, 3 liters at 25,000 feet, and 7.6 liters at 40,000 feet. Descent would be necessary in order to obtain relief.

In one experiment, 200 cc of air was placed in the stomach at ground level by means of a stomach tube. A roentgenogram (x-ray) was made (figure 19*a*) and a subsequent roentgenogram was made a few minutes later at a simulated altitude of 40,000 feet (figure 19*b*), care being taken not to expel any of the gas. Marked distention of the gas of the stomach occurred and some of the gas overflowed into the small intestine. The same phenomenon could be demonstrated if the gas were placed initially in the small or large intestine.

Ordinarily, the effect of expansion of gas on an individual during flight would depend on the amount of gas present initially and also on the rate of ascent. With the average amount of gas and a rate of ascent of less than 1,000 feet per minute, fullness and distention usually occur at 20,000 to 25,000 feet. At this point, or slightly lower, belching usually occurs and there is an urge to pass flatus. As ascent is continued, the above effects tend to persist. At about 30,000 feet there may be abdominal cramps. As the gas is expelled, it is replaced volumetrically by the expansion of the remaining gas, and this process repeats itself until the ultimate altitude is finally reached. At this point, gas will continue to be expelled intermittently for an hour or two, until the remaining gas has reached a volume approximately equivalent to that which it had initially at sea level, after which the abdominal distention disappears and the abnormal belching and passing of flatus will no longer occur. When a large amount of gas is present originally, the symptoms will occur at a lower altitude.

During ascent at higher rates of climb, such as 1,000 feet per minute or more, gas tends to remain localized in pockets in the intestinal loops instead of moving downward and being expelled. As a result, the abdominal distention is increased considerably, and at 15,000 feet to 20,000 feet one may begin to suffer from abdominal cramps of varying severity. At 30,000 to 35,000 feet these cramps occur fairly often, and if the gas tends to move along the intestinal tract at all, it travels very slowly. Walking and moving about in the airplane or low-pressure chamber often causes the gas to move on and to be expelled.

The importance of dietary regulation and the avoidance of such gas-forming foods as dried beans and cooked cabbage, and the need for evacuating the bowels before flying are well known. In a recent questionnaire sent to 500 patients as to the foods that actually gave them gaseous distress, it was found that most of the persons complained of onions and, next in order of frequency, the foods most commonly blamed were cooked cabbage, raw apples, radishes, dried beans, cucumbers, milk, fatty or rich foods, melons, cauliflower, chocolate, coffee, lettuce, peanuts, eggs, oranges, tomatoes and strawberries. Actually, any food can be the offender, and it can be identified and incriminated only by each individual's keeping a record of different foods eaten a few hours before flights when bloating occurs. Overeating is a frequent cause of gaseous distress. Some individuals who have an unusually sensitive bowel suffer from gas when they are coming down with a cold. Many persons with diarrhea have an associated gaseous distress.

PREVENTION OF DISTRESS.—Prevention of distress from the expansion of gas in the stomach and intestine usually can be accomplished by determining the type of food that causes an unusual amount of gas to accumulate and, in addition, eliminating the notoriously gas-forming foods from the diet prior to high-altitude flights. If possible, meals should be eaten at regular hours, and overeating and the eating of cold foods should be avoided.

Figure 19a—X-ray photograph, taken from the front of the body, of the stomach at ground level, after the introduction into the stomach of 200 cc of gas.

Figure 19b—Appearance of the stomach in figure 19a as seen at a simulated altitude of 40,000 feet. Air shows as a darker area in the photograph.

CHAPTER VI

THE EFFECT OF ACCELERATION ON AVIATORS

Principles of Physics

A clear understanding of the effects of acceleration on flying personnel requires a knowledge of the physical forces involved. Acceleration is a generic term for "a change in velocity," either as regards magnitude or direction, or both. When velocity increases, the change is properly called an acceleration but when velocity decreases the term deceleration is better. Three types of acceleration and deceleration are encountered in flying, namely, *linear,* involving change of speed in a straight course, *angular,* or change in rate of rotation, and *centripetal,* which depends on rate of change of direction and velocity in a curved flight.

LINEAR ACCELERATIONS.—Linear accelerations, or decelerations, are those in which the magnitude but not the direction of the velocity is changed. Examples of their occurrence in aviation are: take-offs, landings, catapult take-offs, crash landings, and parachute opening impacts. It can be seen that in some of these examples the body is subjected to increases in velocity, whereas in others it is subjected to decreases in velocity. Except for the serious results of crash landings, linear accelerations and decelerations produce no important problems in aviation medicine.

ANGULAR ACCELERATIONS.—Angular accelerations, such as produced by spins, affect the body chiefly in that they produce dizziness. This problem will not be considered herein.

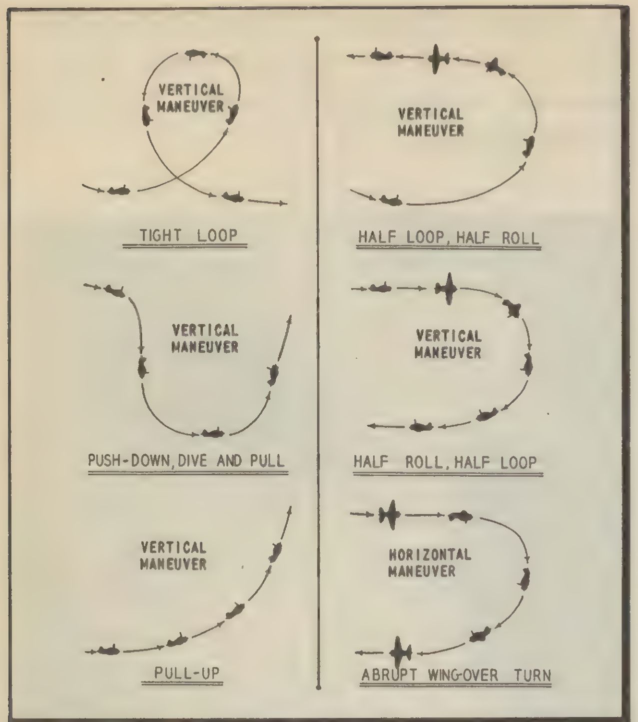


Figure 20—Six typical airplane maneuvers.

CENTRIPETAL ACCELERATIONS.—Centripetal or radial accelerations, because of their pronounced effects on the human organism, are given chief consideration in this chapter. A body, such as an airplane and its occupant, which describes a circular path, is subject to an acceleration which is called "radial" or "centripetal," and which is directed toward the center of rotation. This acceleration sets up a force of inertia called "centrifugal force," acting in the opposite direction. This centrifugal force is proportional to the extent of the centripetal acceleration. Examples in aviation involving centripetal or radial acceleration are: turns, interruption of dives, loops and the like (figure 20). The amount of centrifugal force engendered in these maneuvers is directly proportional to the square of the linear flight velocity of the aircraft and is inversely proportional to the radius of its curved path; that is, the shorter the radius of turning, the greater the resultant centrifugal force.

As a convenient measure of centrifugal force, the unit representing acceleration due to gravity, that is, 32.174 feet/second^2 is used. This is represented by the symbol g. By common usage, accelerations which produce forces upward on an airplane perpendicular to its line of flight, are called *positive accelerations,* and those directed downward are called *negative accelerations.* However, a force acting in one direction on the airplane produces an equal but opposite reaction on the occupant. Thus, in *positive accelerations,* when the airplane acts upward on the body in the direction of seat to head, the inertia of the body acts in the direction of head to seat. The centrifugal force encountered is expressed in the term of $+g$. Conversely, in *negative accelerations,* when the airplane acts downward on the body in the direction of head to seat, the inertia of the body acts in the direction of seat to head. The centrifugal force in this case is expressed in terms of $-g$ (figure 21).

Subjective and Objective Observations of the Effect of Centrifugal Force

In any discussion of this nature, certain criteria must be considered. What is important is not only the extent of the centrifugal force involved, but also the duration of the action of the force and the direction in which it is acting upon the subject. Centrifugal forces acting transversely to the long axis of the body are relatively harmless whereas those acting parallel to the long axis of the body can cause disturbances, if they are sufficiently great. The duration of action of centrifugal forces is important, since greater forces can be tolerated provided time of exposure is shortened.

EFFECTS OF ACCELERATIONS ACTING TRANSVERSELY TO LONG AXIS OF BODY.—Human subjects* have been able to withstand $+12$ to $+14$ g acting transversely for 120 to 180 seconds. Visual disturbances may occur above $+14$ g. They are similar to those which will be discussed later. Interference with respiration and even inability to breathe, especially when the forces act in the direction of chest to back, are the chief discomforts incurred in transversely acting centrifugal forces. In actual aeronautical practice, since the conventional seat puts one in the upright position, the centrifugal forces encountered always act approximately along the long axis of the occupant of the aircraft. In order to have centrifugal forces acting transversely on the aviator, flying personnel would have to be placed in the prone or supine positions. However, neither position is possible in present conventional aircraft, except for certain members of the air crew.

* These data have as a basis studies carried out on subjects in a human centrifuge, which is a laboratory device used to obtain high centrifugal forces. This apparatus usually consists of a horizontally rotating superstructure, at the ends of which cockpits are suspended.

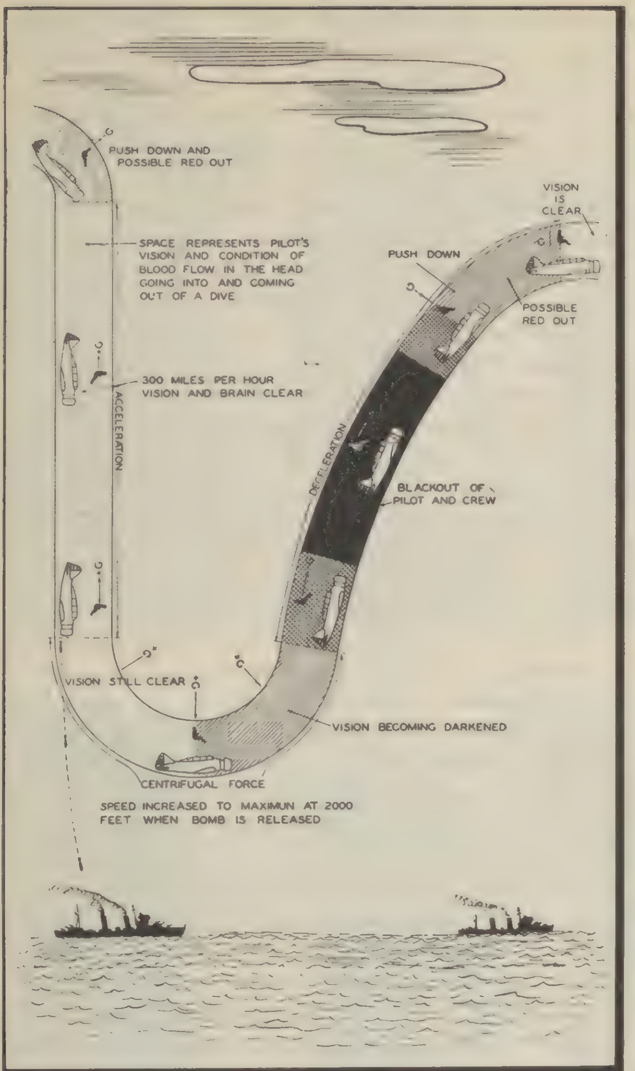


Figure 21—The effects of acceleration, deceleration, centrifugal force and "push-down."

EFFECTS OF POSITIVE ACCELERATIONS.—Centrifugal forces acting in the head to seat direction result from *positive accelerations.* The subjective effects of *positive accelerations* can be summarized as follows: At lower centrifugal forces, such as +2 *g,* the subject is pressed firmly into the cockpit seat; at +3 to +4 *g,* movement of the extremities becomes difficult or impossible; the soft tissues of the face and the body are drawn downward; at +4 to +5 *g,* acting over a period of three to five seconds, visual disturbances begin to make their appearance. The visual disturbances are, first, blurring, or "graying" of vision, followed by "blacking-out" or complete loss of vision (figure 21). The impairment of vision may not go beyond "graying" for any given value of *g.* However, should the centrifugal force be increased or the length of time of its action be increased, "black-out" will be encountered. Other disturbances occurring in association with the "black-out" may be a decreased sharpness of hearing and an increased reaction time. At or above +5 or +6 *g,* acting for three to five seconds, consciousness is lost. Except when consciousness is lost, symptoms disappear almost immedately on cessation of the centrifugal force. Should consciousness have been lost, a period of five to ten seconds or more of confusion and disorientation results. Among subjects undergoing *positive acceleration,* an increase in pulse rate simultaneous with the onset of centrifugal force, together with a decrease in blood pressure was found (figure 22). Should the centrifugal force be moderate in severity (for example, +3 to +4 *g*), and should it be prolonged for more than a few seconds, there will be a rise in blood pressure. The increase in pulse rate and the somewhat delayed rise in blood pressure are compensatory mechanisms elicited by the body in order to maintain normal circulation. The respiratory rate similarly increases up to thirty per minute. This also is in the nature of a compensatory change.

The physiologic basis for the foregoing observations is a lack of effective circulatory volume. The visual and other disturbances resulting from *positive acceleration* are due to the decreased blood supply to the brain. There are several theories underlying the reason for impaired circulation of the eyes and brain. However, the following explanation appears most reasonable: The fact that the large blood vessels of the body lie in a direction of head to seat (figure 23), and the fact that they are

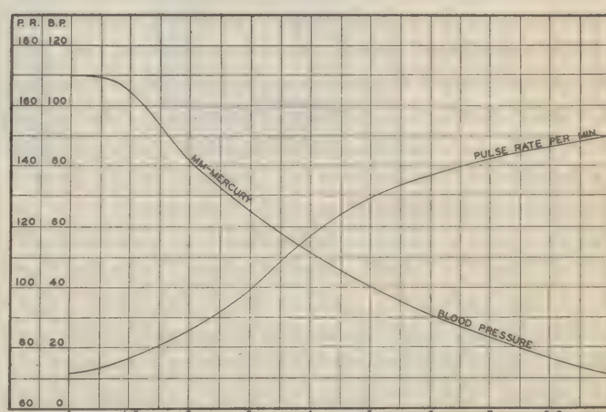


Figure 22—The effects of acceleration (+ g) and centrifugal forces upon blood pressure and blood rate.

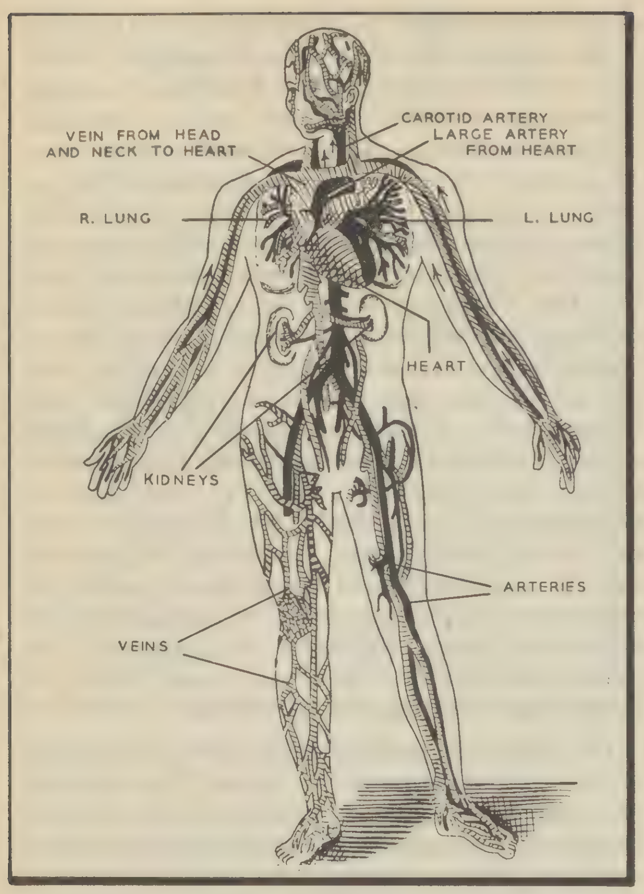


Figure 23—Distribution of the blood of the body, showing the veins and arteries. In this picture it can be easily seen that the long axes of the veins and arteries for the most part have a head to seat direction.

elastic tubes, rather than rigid conduits, are responsible for the shifting downward of the blood contained within the walls of the vessels when the aviator is subjected to high centrifugal forces. At the lower end (in the head to seat sense) the blood vessels dilate because the hydrostatic pressure is greater at that end. The veins, rather than the arteries, are dilated most. This results in a downward displacement or "pooling" of the blood. It has been determined that in the vicinity of $+7$ *g*, as much as a pint of blood may be displaced into each leg. To this must be added blood displaced into the vessels of the abdominal cavity. With the blood thus distributed, there is an inadequate return of blood to the heart. Hence, the output of the heart is considerably less than normal. This, in turn, results in a reduced blood pressure. With the falling-off of blood pressure, the circulation to the brain also decreases proportionately. Considerable evidence has also been advanced by German workers which points to the fact that another factor must be considered. The column of blood between the heart and the brain is approximately 30 centimeters (12 inches) in height. At $+5$ *g*, the centrifugal force has increased the weight of the blood five times; thus for blood to reach the floor of the brain from the heart, as it does normally, the labor demanded of the heart would be that required to push a column of blood upward 150 centimeters (60 inches). In summary then, the impaired circulation of the brain is a combination of downward displacement of blood plus an increased work load on the heart, due to the hydrostatic effect of centrifugal force on the column of blood between the heart and brain. X-ray evidence obtained in experiments on animal subjects in centrifuges and on human subjects in aircraft substantiates the fact that there is downward shifting of the blood and a decrease in filling of the heart due to centrifugal forces resulting from positive accelerations (figures 24*a* and *b*).

A discussion of *positive accelerations* would not be complete without clarification of the fact that "graying" or "blacking-out" occurs at a lower value of $+g$ or at a shorter duration of any given value of $+g$ than does unconsciousness. The normal eyeball has an internal pressure of approximately 18 millimeters (about one-half inch) of mercury. Therefore, the arteries supplying blood to the retina of the eye must overcome this 18 millimeters of counterpressure before any blood enters this area. There is no such counterpressure in the brain proper; hence, during the action of centrifugal forces, the blood pressure eventually decreases to a point at which it is still effective in maintaining circulation in the brain, but can no longer effectively maintain circulation to the retina of the eye. Furthermore, it has been shown that the retina is more sensitive to the lack of oxygen than is the brain tissue. Ultimately, of course, it is a lack of oxygen which underlies the effects on vision and consciousness. Without adequate circulation, there is an inadequate supply of oxygen to these vital areas.

At this point, it is also expedient to point out why the tolerance of human beings to centrifugal forces is almost double when they assume the prone position—that is, when the centrifugal force acts at right angles to the long axis of the body. As was brought out briefly in the foregoing discussion, the long axis of the main blood vessels of man are parallel to the long axis of the body (figure 23). Hence, centrifugal force acting in this direction displaces blood upward or downward, depending upon the direction of the action of the force. With the subject in a prone or supine position, the centrifugal force would be acting at right angles to

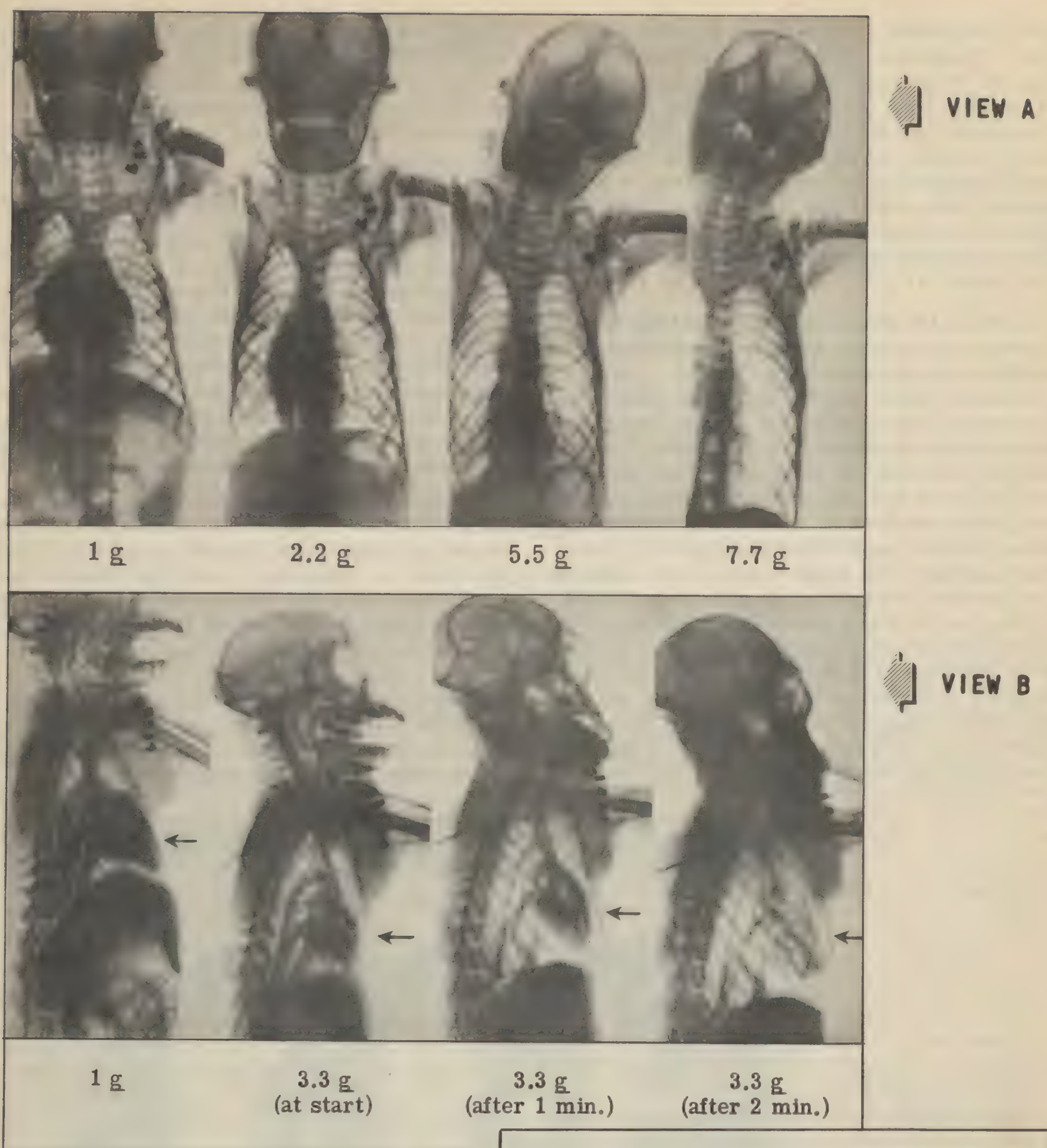


Figure 24a—Front view and, b, side view of alteration in filling of the heart as the duration of centrifugal force exerted in the direction head to foot increases. (After Fischer from Ruff and Strughold: A Compendium of Aviation Medicine.)

these great vessels, and would thus cause no displacement of large masses of blood. X-ray evidence obtained in study of animal and human subjects again comes to our aid, for it has been demonstrated that no shift of blood takes place and filling of the heart remains normal at extremely high accelerations, provided the subject is undergoing the stress while he is in a prone or supine position and provided that the direction of the centrifugal force is perpendicular to the long axis of the body, and therefore to the great blood vessels of the body (figure 25).

EFFECTS OF NEGATIVE ACCELERATIONS.—In this type of acceleration, the limit of man's tolerance is reached at the comparatively low values of -2 to -3 *g*. An aviator exposed to such a force suffers from ocular and cerebral congestion. There is a "gritty" sensation in the delicate membranes which line the inside of the eyelids and the eyeballs in front; the eyeballs feel as if they would pop from their sockets, and there is a throbbing pain in the head. At -3 *g*, a condition of seeing red or "red-out" has been described (figure 21). Symptoms may persist for several minutes to several hours after exposure to *negative accelerations*. Serious complications, such as retinal and cerebral hemorrhages, can be anticipated if values exceeding -3 *g* are encountered while the aviator is undergoing negative acceleration. Objective symptoms are a decrease in pulse rate and no particular change in the blood pressure. The physiologic basis for the symptoms is a shifting of the blood toward the head end of the body, since the centrifugal force is now acting in that direction. Unfortunately, the cranial cavity is rigid and does not permit of much pooling of blood; hence, the serious difficulties encountered during *negative accelerations* at comparatively low centrifugal forces.

Methods of Increasing the Aviator's Tolerance to High Centrifugal Forces

It is, of course, of paramount importance to minimize, if possible, any of the stresses placed upon the aviator. For this reason, it is perhaps best to state at first that one should avoid maneuvers which would induce high *negative accelerations,* such as outside loops. The next thing that comes to mind is alteration of position of the aviator, since it has been shown that forces acting transversely to one's long axis are tolerated rather well. This is not expedient in present conventional aircraft, but modifications of this principle have been used.

The crouch position (figure 26) has been used by both the Germans and the British. This position is facilitated by elevated rudder bars or a lowered cockpit seat. While the aviator is undergoing a centrifugal force, as in pulling out from a dive, the trunk of the body is bent forward on the thighs; the head is drawn back somewhat so that one can still see ahead to some degree. The crouch position is effective because it accomplishes two things: first, it lowers the hydrostatic column between the heart and the brain, and second, it reduces the reservoir into which blood might be pooled, by placing the body in a somewhat transverse position in rela-

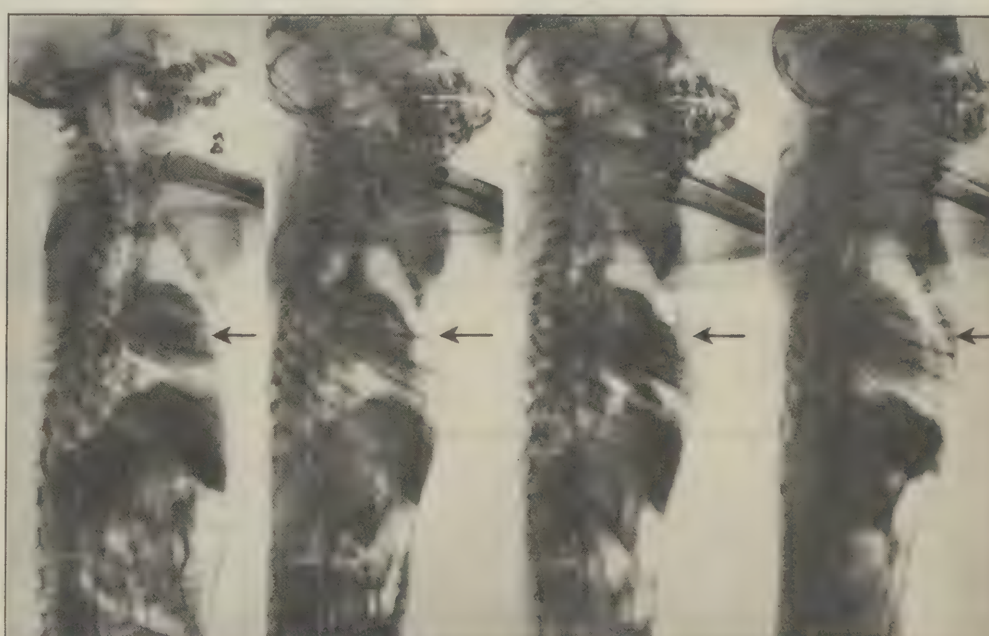


Figure 25 — No alteration in filling of the heart as acceleration in the direction front to back increases from 1 g to 2.2 g to 4.4 g and 6.6 g, respectively. (After Fischer from Ruff and Strughold: A Compendium of Aviation Medicine.)

tion to centrifugal force. It is estimated that an increase of from $+1$ to $+2$ g in individual tolerance can be obtained by this measure.

Factors which decrease one's tolerance to high centrifugal forces are: fatigue, excessive smoking, drinking to excess, loss of sleep, anoxia and debilitating conditions such as colds and diarrhea. Therefore, these should be avoided by flying personnel who anticipate undergoing the stress produced by high centrifugal forces.

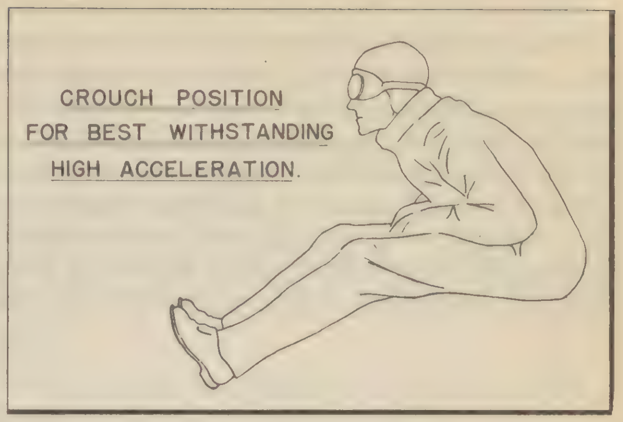


Figure 26—The crouch position, used much by German and British aviators. (From Von Diringshofen: Medical Guide for Flying Personnel.)

CHAPTER VII

AIRSICKNESS

CAUSE.—The mechanism of airsickness or, more properly, of motion sickness (since it differs little from seasickness, train-sickness, swing-sickness, and so forth) cannot be fully understood unless reference to the underlying physiology is made.

The internal ear (figure 16*a*), besides containing the sense organ concerned with hearing, also contains the organ of equilibrium (the "labyrinth"). This organ of equilibrium, in turn, has two functions. First, it enables us to perceive the direction of gravity at any moment, and second, it enables us to determine change of direction in response to movements of rotation. The organ of equilibrium of the internal ear is intimately bound up with the rest of the nervous system, and its impulses, together with those from the nerves of the skin, muscles and joints, enable one to control movements of muscles in order to maintain equilibrium in every position of the body. Muscles of the eyeball also are controlled, so that while the body turns, objects may be perceived as if they stood still, and orientation in space is maintained. This organ of equilibrium, together with the organ of sight, forms the controlling mechanism for the maintenance of human equilibrium.

The visual and equilibratory sense organs are united closely by means of nerve pathways. Because of this relationship, they may be the source of many false conceptions, especially in blind flying. The apparatus of the ear is not able to distinguish between *gravity* which it normally encounters and *accelerations* which occur in flight. The eyes, on the other hand, are controlled in part by what we see and in part by nerve impulses from the internal ear. Therefore, in flight it is not unusual to have sensations coming from the internal ear which are in contradiction to those sent out by other sensory organs. The brain then may receive nerve impulses which are confusing and contradictory. This is the chief basis for airsickness. Persons who have insensitive organs of equilibrium tend to be less affected by airsickness caused by motion, than persons who have sensitive organs, because in the former persons opposition is less likely to occur between impulses from the internal ear and the eye. People who have sensitive organs of balance are more likely to become upset by pitching and rolling motions, such as are encountered in flight. Among the contributing factors to airsickness are noxious odors (such as the odor of gasoline), cold, noise, vibrations, lack of visual orientation and undue sensitiveness of the nervous system because of the psychologic factors such as fear of flight.

SYMPTOMS.—The symptoms of airsickness can be listed as follows: yawning, belching, pallor, salivation, abdominal discomfort, sweating, nausea, retching, vomiting, headache, malaise, apathy, distaste for flying and disinclination toward activity.

TREATMENT.—The present treatment of airsickness is rather unsatisfactory. The multitude of remedies available, both through the drug market and through physician's prescriptions, indicates that none is particularly effective. However, there are several measures which are of value. When it is tactically possible, the pilot should first seek a smooth stratum of air. Other measures may be enumerated as follows: (1) warm and comfortable clothing, (2) cushions to help avoid the effect of vibrations, (3) cotton plugs in the ears to reduce the noise level, (4) a diet free of greasy foods and excessive liquids, (5) maintenance of good visual reference whenever possible, to avoid spatial disorientation, (6) occupation of a station in the aircraft as close as possible to the center of gravity, (7) ventilation of the airplane when noxious odors are present, and (8) oxygen.

The majority of individuals can become acclimatized to the type of motion produced by airplanes, and thereby become resistant to airsickness. Those less fortunate usually are eliminated from flying training.

CHAPTER VIII

FLYER FATIGUE

In previous writings, the entity to be discussed below has been referred to as "pilot fatigue." It is obvious that the bombardier, the navigator, the radio operator and the gunner are likewise subject to similar fatigue. The recent Army Air Forces Memorandum No. 65-23 of July 2, 1942, includes all personnel on flying status under the term "flyer." Hence, "Flyer fatigue" seems a better designation than "pilot fatigue."

DEFINITION.—Fatigue is a progressive decline of man's ability to perform his appointed task. It may make its presence known by deterioration of the quality of his performance, or by his inability to keep up with the rate of work required of him. Although the principal cause of fatigue is the time already spent on the job, many other factors strongly influence the time of its appearance. Uncomfortable or dangerous working conditions, attendant emotional strain, the rigors of climate, insufficient oxygen for the body's needs and poor general health all contribute to the early onset of fatigue. Postponement of the onset of fatigue depends largely on elimination of these contributing factors.

Combat conditions, and indeed military flight missions of all kinds, demand the best performance of each member of the crew. Since the fatigued flyer reacts slowly, makes judgments inaccurately and performs coordinated muscular acts jerkily, it is of paramount importance that fatigue be eliminated.

CLASSIFICATION.—A scientific analysis of the foregoing outline would break it down into diverse component parts. The fatigue of muscles is well exemplified by the effects of the excessive playing of tennis or of a day spent in digging a ditch. The muscles feel full; actual aching may occur. In the vernacular, "one's bones ache." The capacity for muscular effort is reduced. After a day of rapid typing, the stenographer says her "bones ache," yet her fatigue can hardly be described as "generalized muscular fatigue." We might break her condition down into two components: (1) postural fatigue, arising from sitting cramped over her machine too long, and (2) neuropsychologic fatigue. The latter includes failure of attention and boredom arising from long hours of uninterrupted sameness. It includes fatigue of her eyes caused by the strain of watching type and notebook, fatigue of her ears arising from working beside a punch press or from trying to hear recorded voices in the dictaphone over the hubbub of the office. To these must be added a co-ordinative fatigue, a lessened ability to perform delicate muscular movements requiring no particular strength but exact timing and force of action. All these are manifestations of "acute fatigue"; fatigue which arises in the course of the day's tour of duty.

Very different is the state of "chronic fatigue." The condition of the mother who has conducted three children safely through a long attack of typhoid fever is an example. Although the crisis is past, and the children are on the mend, and although she has had several days' rest, has regained normal periods of sleep and some of her lost weight, she still finds herself unable to perform as had been her wont. She tires easily. The slightest unlooked-for incident evokes an exaggerated emotional response. She cries easily and worries about minor problems which ordinarily would not trouble her: She

finds sleep elusive and her appetite slight. This is "staleness." The term "staleness" is a brief name for "chronic fatigue" which is useful in that its implications keep fresh in one's mind the nature of the condition.

ACUTE FLYER FATIGUE.—Thus, we arrive at two general kinds of fatigue—"acute fatigue" with at least muscular, postural, and psychologic components, and "chronic fatigue" or "staleness." How do these types apply to the fatigue seen in flight personnel? The acute fatigue of pilots has a clear, although small, muscular element. It has a large element of boredom arising from monotony. The sensory apparatus becomes fatigued by hours of ranging the eyes over the instrument panel and by hours of listening to radio over the continuous power hum. To this must be added the emotional strain of the necessity for constant alertness. It is obvious that the resulting fatigue centers in the nervous system. Bombardiers and gunners are subject to similar acute fatigue.

CHRONIC FATIGUE. — The incidence of chronic fatigue or "staleness" is much less than acute fatigue, but its elimination is both more difficult and more time-consuming than that of acute fatigue. There are two periods in the flying history of the individual when it is likely to appear. The first is early in his tactical flying experience after fifteen to twenty-five hours of combat and the second is after 100 to 125 hours. That the real cause is emotional strain is clearly seen from the fact that equal periods of nontactical flying have no such effect. The individual finds his sleep unsatisfying, his appetite variable; he feels a distate for flying and a lack of confidence in his abilities. His reactions are slowed and his judgment is neither as positive nor as dependable as normally. Most men dislike to report this condition. They feel that something degrading is connected with it. Actually, the condition affects perfectly normal persons and must be carefully and sympathetically treated when its occurrence cannot be forestalled.

TREATMENT OF CHRONIC FATIGUE. — Treatment is most productive when efforts are concentrated on prevention. In the Army Air Forces the occurrence of chronic fatigue has been successfully reduced by means of stringent regulations as to rest, diversions, leave and intervals between combat mission. In Army Air Forces Memorandum No. 25-4, Headquarters, Army Air Forces, Washington, June 30, 1942, it is specified that bomber crews shall have a minimum of twenty-four hours of rest between missions and that fighter pilots shall be on first call no more than eight hours of each day. Furthermore, a period of leave and of alternate duty is to follow each tour of operational flying. A maximal tour of operational flying is defined as 100 hours spent in a fighter mission or 125 hours spent in a bomber mission or their time equivalents: six weeks and three months, respectively. The specified leaves are not to exceed seven days, because this seems to be an optional period. Under combat conditions, it is urged that flyers be quartered at least three miles from the airdrome. Provision for athletic sports in off hours should be made.

These measures have proved to be extremely effective. Those few instances of staleness which do occur are treated as soon as possible. It is important to realize that the man who has the condition does not get better spontaneously. The continuance of duty after the signs of chronic fatigue appear is hazardous, whereas under proper treatment the condition rapidly clears and is forgotten; if neglected, the man may never again be fit to fly. Adequate treatment demands hospitalization, complete rest, and freedom from strain. Even the mildest degrees demand a complete change of scene and relief from duty of the more arduous types.

TREATMENT OF ACUTE FATIGUE.—The normal man recovers from acute fatigue spontaneously and quickly. A night's comfortable sleep, a bit of diversion and adequate and satisfying meals are all that is required. Our efforts in the problem of acute fatigue are devoted to postponing as much as possible its onset. If this is done, more useful work will be accomplished. Fatigue of a serious degree will be postponed or perhaps avoided completely.

To this end, the physicist and the engineer, the physiologist and the physician are collaborating to reduce the fatiguing factors. Improvement of seating comfort, reduction of strain on eyes and ears and improvement of oxygn equipment are examples of their efforts in this direction. The latter is very important, as appears in chapter III, because even slight degrees of oxygen-want hasten the onset of fatigue. Clothing is being improved to protect against the wide variations in temperature which flyers must endure, as set forth in chapter X. The fact that temperatures at 30,000 feet are well below 0 degrees F even on "hot days" demonstrates the necessity for attention to conservation of body heat. Cold has profound effects on the body. Oxygen requirements are greatly increased by it. The shivering produced makes nice muscular coordination difficult. The result is that fatigue ensues quickly when one works in the cold.

It was mentioned above that fatigue of the nervous system is the strongest element in pilots and gunners alike. This type of fatigue is readily thrown off by rest periods of a few minutes, if the fatigue is not permitted to pile up. It is, therefore, of paramount importance in multiplace airplanes that the individuals be urged to rest a few minutes every now and then, whenever the tactical situation will permit. To the tail and turret gunners who in some ships still must work in a cramped and invariable posture, these short rest periods are especially important. The process of maintaining a fixed posture is extremely fatiguing.

During such rest periods the men should be urged to move about as much as circumstances will permit. The alleviation of boredom and monotony as well as of physical factors of fatigue is greatly aided by the eating of candy or other appetizing food during these same respites.

DRUGS IN TREATMENT.—The possibility of using medications to postpone the onset of fatigue is also receiving much attention. The ideal drug for the purpose would be one which would sharpen the wits, avert sleepiness and improve man's feeling of well-being. The man who has taken the drug must not be left worn out when it wears off. At the same time, the drug must be effective by mouth and harmless, not habit-forming, in the dosages required for military purposes.

Stories are legion of the phenomenal mental feats certain men have been capable of performing under the influence of cocaine, yet no one would be so lacking in foresight as to use this substance for our purpose. It is both damaging and habit-inducing. There are now under test, however, certain substances of considerable promise. If their merit and harmlessness can be clearly established, their distribution to flight personnel can be expected.

SUMMARY.—Fight against fatigue is being won through:

1. Utilization of young men in the prime of good health (these are least subject to fatigue).

2. Maintenance of the best possible living and working conditions.

3. Careful attention to rest, recreation, and sports.

4. The development of fatigue-alleviating substances.

5. Proper spacing of tours of duty, of individual missions and of leaves.

6. Early diagnosis and proper treatment of all instances of staleness.

In addressing a group as intelligent as members of the United States Army Air Forces, it seems unnecessary to add that the effectiveness of a treatment is never any better than the zeal with which one applies it. Just as the best possible oxygen apparatus is useless if the pilot does not put it on when indicated by his altimeter, so also, the best plans for the reduction of fatigue would accomplish little without the personal cooperation of the flight personnel. Just how well members of our air forces have accepted this responsibility is clearly seen in our low rate of fatigue.

CHAPTER IX

NIGHT VISION

Night vision is of great importance in all military operations not carried out in daylight. It is the purpose of this section to point out some of the little known peculiarities of night vision, so that better use may be made of this type of vision by personnel of the United States Armed Forces.

Let us consider how night vision differs from day vision, the factors which affect it, how it can be improved, and, in general, how we can best use it to our advantage.

HOW NIGHT VISION DIFFERS FROM DAY VISION.—Night vision differs from day vision in that night vision is accomplished with the periphery of the field of vision; that is, we see things best in very dim light if we look to one side of, rather than directly at them. In bright light we see things best when looking directly at them. But the center of the retina, where we see best in the daytime, is not the most sensitive part of our eye for seeing at night. This central region of lesser sensitivity in dim light covers an area of about 5 to 10 degrees in the center of our vision, and outside

that area the sensitivity is fairly constant out to about 40 degrees from the center. Thus, for night vision it is almost as if we had a "night-blind spot" in the center of our eye, and unfortunately most of us are not aware that this "night-blind spot" exists.

True perception of color is not possible with night vision, as a man may soon discover if he attempts to determine the color of objects at night. One may distinguish between a light and a dark color at night by the difference in the intensity of reflected light. This, however, is not perception of color, but is simply recognition of two different shades of gray.

Perception of fine detail with night vision is likewise impossible. At night we can see only the rough outline of an object, and this only when it is large and makes a big image in the eye.

It seems pertinent to point out that there are two separate types of nerve elements in the eye which are responsible for day and night vision and which account for the differences noted above. One factor is the *cones,* which are responsible for day vision. The cones are most numerous in the center of the retina and thin out very rapidly toward the periphery. We see very fine detail and colors with the cones, but they are not very sensitive to dim light. The other factor is the *rods,* which are most numerous in the periphery (away from the center) of the retina and become less numerous toward the center. In dim light rods are about 1,000 times more sensitive than the cones, but colors and fine detail cannot be seen with the rods. There are almost no rods in the center of the eye, a fact which accounts for the "night-blind spot," mentioned above.

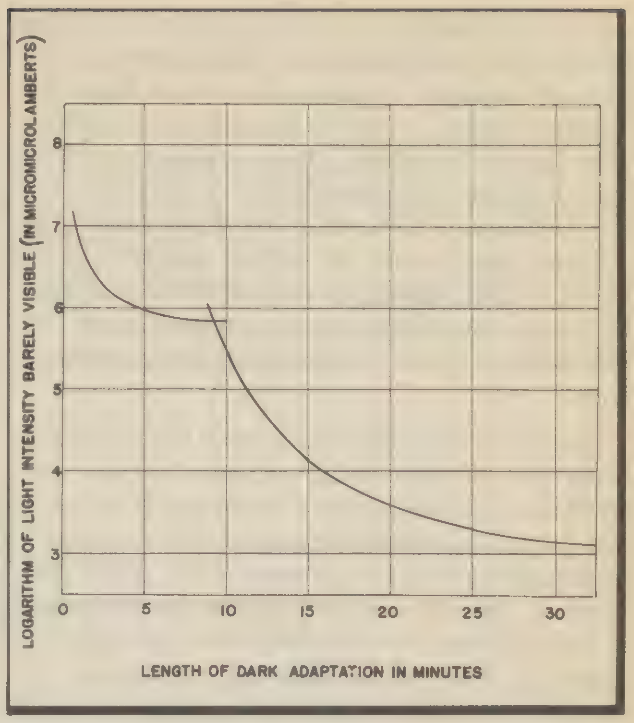


Figure 27—The curve of dark adaptation to dark when a person enters the dark from a brightly lighted room. The curve represents the least amount of light which can barely be seen at various intervals after the person enters the dark. The decline of the curve indicates that the brightness of light just perceptible is becoming less; hence the greater is the sensitivity of the eye. It will be noted that a 10,000 fold increase in sensitivity is attained in the first thirty minutes; beyond this time little change occurs. Essentially, this same curve and increase in sensitivity can be obtained by wearing red goggles in a normally lighted room.

FACTORS WHICH AFFECT NIGHT VISION.—Adaptation to dark.—The experience of going from a bright environment into a dimly lit or darkened room is familiar to anyone who has entered a movie theatre during the matinee show. At first one can see almost nothing in the dimly lit theatre, but after fifteen minutes or so one is able to see rather well; in fact, well enough to recognize friends who may be seated nearby. This improved vision is due to an increased sensitivity of the eye. The process through which the eye goes in gaining this increased sensitivity is called *adaptation to dark.* The process is only partly completed in the theatre, since considerable light prevails therein. If the individual is then placed in an absolutely dark room the sensitivity of the eye will increase still further. The complete course of adaptation to dark when one goes from a bright environment into a fully darkened room is shown in figure 27. The curve is obtained by measurement of the amount of light which can just barely be seen at various time intervals after entry into the dark room. The lower the curve goes, the lesser is the brightness of light perceptible, and hence the greater is the sensitivity of the eye. The change in the amount of light just barely visible at the beginning of the curve and after thirty minutes indicates a 10,000 fold increase in sensitivity. It will be noted that the rate of decline beyond thirty minutes is very small, and that the sensitivity does not improve greatly thereafter. Although it requires about thirty minutes to attain this maximal sensitivity, it can be lost entirely by a short exposure to the original bright environment; and the whole thirty-minute process of dark adaptation would then have to be repeated in order to regain maximal sensitivity. If the brightness of the light to which one was exposed

were less, it would not take long to adapt to darkness, because then one would start farther down on the curve. For example, in going from a movie theatre into absolute darkness, it takes only about ten minutes to adapt to dark completely. Thus, in preparing for any night operation one should adapt to dark for at least thirty minutes. In an airplane one should keep all unnecessary lights turned off and all essential lights as dim as possible. Reading of dials should be done rapidly, so as to affect adaptation to dark the least. The aviator should not stare at the instrument panel unnecessarily.

VALUE OF RED-LENSED GOGGLES.—It has been found that red light affects adaptation to dark much less than does any other color. This factor is so marked that by wearing red-lensed goggles in a normal, artificially lighted room one can attain nearly perfect adaptation to dark and at the same time see well enough to read newsprint. The potential advantages which may accrue as a result of this discovery are numerous. For example, one can wear red-lensed goggles for thirty minutes before a mission, removing them in darkness preparatory to the take-off, and be assured of good adaptation to dark for the flight; or red lights can be used for lighting in airplanes to provide the same or more light with less spoiling of adaptation to dark than with light or other colored lights; or red-lensed goggles can be used temporarily when an aviator is caught in searchlight beams, so that his adaptation to dark will not be spoiled by the glare.

EFFECT OF ALTITUDE ON NIGHT VISION.—The ability to see well at night is decreased by exposure to altitudes. The higher the altitude, the greater is the effect. At 12,000 feet, with a flyer breathing atmospheric air without supplemental oxygen, night vision is only about a half as good as it is at sea level. This effect is due to anoxia and can be entirely overcome by the use of supplemental oxygen. For this reason the use of supplemental oxygen at altitudes *from the ground up* is required on all night flights (Army Air Forces Regulation No. 60-7, dated February 2, 1942).

EFFECT OF FOOD ON NIGHT VISION.—Vitamin A is a chemical factor which is essential for good night vision. This vitamin is supplied plentifully in Army rations, and the only precaution which need be taken concerning the subject is that each individual know and eat the foods served which contain vitamin A or its precursor, carotene. Foods high in vitamin A content are eggs, butter, cheeses, liver, apricots, peaches, carrots, squash, peas, spinach and all types of greens. Cod-liver oil and greens are richest in vitamin A. Some of these foods surely will be served from time to time and should be eaten, especially if one is likely to be involved in night operations. An excess of vitamin A will not improve the night vision of a normal individual who is already getting enough of it; neither will an excess do any harm. When conditions make impossible the provision of foods containing vitamin A in a quantity sufficient to maintain good night vision, supplemental doses of this vitamin will be provided through the quartermaster as directed by the flight surgeon. Multivitamin capsules contain vitamin A (Medical Department Supply Catalog, Item No. 1.K61500). (See Army Air Forces Memorandum No. 25-5, dated July 14, 1942, for further details.)

INDIVIDUAL VARIATIONS IN NIGHT VISION.—The increase in night operations in modern warfare has shown that there is a considerable variation among normal individuals with regard to their ability to see well in very dim light. This difference is such that those with the best vision can see well with only a tenth the illumination required by those with the poorest vision. This obviously is a very great and significant difference, and it is planned that some use will be made of it in the selection of personnel with very good night vision for especially important missions at night. Night vision can be improved in almost all individuals by practice in looking off-center when an attempt is made to see things in very dim light. This can be done outdoors at night. With practice, some individuals can double their night visual efficiency.

WINDSCREEN AND LIGHTS WITHIN THE PLANE.—In looking through the windscreen of an airplane, the flyer's ability to see dimly illuminated objects is decreased as the result of two factors: (1) a decrease in the light coming from the object to the eye, due to light absorbed and reflected by the windscreen and (2) a decrease in contrast between the object and its background, due to reflection from the interior surface of the windscreen of any light which may be within the airplane. Since the windscreen cannot be dispensed with, the above factors must be reduced to a minimum. Hence, for night operations, the windscreen must be kept scrupulously clean in order to increase the transmission and to decrease the reflection of light, and the lights within the airplane must be kept turned out or dimmed to the absolute minimal brightness possible for their use.

SUMMARY.—In conclusion, the suggestions given above for improving night visual efficiency are:

1. Develop adaptation to dark preceding any night operation by staying in a dark room or by wearing red-lensed goggles for thirty minutes.

2. Protect this adaptation by not exposing the eyes to any bright light, either inside or outside the aircraft.

3. Keep all nonessential lights within the aircraft turned out, and all essential lights dimmed as much as possible.

4. Use red light in the aircraft whenever possible.

5. Read instruments, maps, and charts rapidly; then look away.

6. Use supplemental oxygen at altitudes from the ground up on all night flights.

7. Eat the foods containing vitamin A that are supplied in the Army rations.

8. Keep all windscreens scrupulously clean.

9. Improve night vision by practicing off-center viewing of objects on dark nights.

CHAPTER X

THE EFFECTS OF HEAT AND COLD ON THE BODY

INTRODUCTION.—As an introduction to the present subject, let us inquire briefly into what range of environmental conditions one is likely to encounter as a flying member of the Army Air Forces.

The warmest temperature one is likely to meet would be that inside a closed airplane grounded in a desert area. On the basis of recent observations made during the month of June inside a B-17-E and a B-24-D at Blythe, California, one of the hottest desert areas in the world, average cabin temperatures of 120 degrees F (or about 12 degrees F above the temperature of the ambient air) were found as a daily maximum. This occurred during the middle of the afternoon. Radiation from the sun in the desert is extremely great, and often ground conditions in and about the airplane become unbearable. At Blythe, crew members were known to have blistered their hands on the outer surface of the airplane, and once a temperature of 165 degrees F was recorded inside the tail turret of a B-17-E. Conditions of maximal temperature inside the airplane usually were reached in only twenty minutes to half an hour after a landing from a flight had been made. Because of radiation at night to the clear skies in the desert, cabin temperatures always decreased below that of the ambient air, sometimes by as much as 15 degrees F. Desert air temperatures also decrease, but not as much as do the temperatures inside airplane cabins themselves.

In the tropics, because of the high moisture content of the air, the radiation intensity from the sun is not so great as it is in the desert, nor, as a rule, are outside air temperatures high. The usual tropical temperature is constant and lies in the range of 80 to 90 degrees F. Here humidities ranging up to 95 percent cause the extreme discomfort from the heat.

Toward the opposite extreme, the coldest temperature one will be likely to tolerate on the ground is from −40 to −50 degrees F. These temperatures occur frequently at Ladd Field, Alaska, for example, during the winter months. Under these conditions the operation and preparation of airplanes for flight are extremely difficult and a serious handicap is imposed on air crews who have to use their hands to perform delicate operations.

In flight, extremely cold temperatures are usually met only above 30,000 feet in turrets and the open waist or tail of a bomber, where present heating systems of planes are not efficient. Outside air temperatures as low as —110 degrees F have been observed, as we saw in chapter II, at the 40,000 foot level over continental United States. Under these conditions, and provided the heating system of the airplane failed completely, it would be extremely unlikely that a pilot could exist for more than a half hour with the present clothing available.

For the above range of temperatures, from +120 to —50 degrees F, it is obvious that no given set of flying clothing would be effective throughout. In preparing ourselves for the effects of heat and cold we try to choose the combination we believe to be the most effective. Aside from clothing, the human body itself

has its own protective devices against cold and heat. Therefore, before an attempt is made to present a detailed discussion of methods of temperature regulation of heat and cold by the human body and how clothing should be used, it seems advisable to review briefly the various mechanisms by means of which the body may gain or lose heat to and from the environment.

HEAT GAIN AND CHEMICAL REGULATION OF BODY TEMPERATURE.—Heat produced in the body as the result of combustion or oxidation of the food in the processes which keep the body alive and active is by far the most important source of heat gain which we need consider. The production of heat as the result of chemical reactions is spoken of as the *chemical regulation* of body temperature. The rate of production of heat when the body is in a reclining and fully rested condition (and twelve to eighteen hours after the last meal) is known as the *basal metabolic rate.* The rate of heat production will be different if measured under conditions different from those stipulated above, but, of course, cannot then be called *basal.*

EFFECT OF EXERCISE OR WORK ON PRODUCTION OF HEAT.—Even the slight amount of exertion required to maintain the body in a sitting position increases the production of heat 10 to 20 percent above the basal rate. The average person uses up about 300 cc of oxygen (STPD) per minute. Moderate exercise, such as walking, may raise the production of heat to three times the basal rate, and extremely hard work or exercise may increase it to ten or fifteen times the basal level. *Shivering* is a form of exercise consisting of the involuntary contraction and relaxation of certain groups of muscles in the body and may increase metabolism to four or five times the basal rate. This is one of the most effective mechanisms which the body possesses for increasing the production of heat and maintaining a constant body temperature under cold environmental conditions. Intense mental effort increases metabolism only a very slight amount.

EFFECT OF INGESTION OF FOOD ON METABOLISM.—The production of heat begins to increase within an hour after food is eaten, reaches a maximal increase of 10 to 30 percent above the basal value at about the third hour and is maintained at this level for several hours. This increase is due to excess energy needed to digest and assimilate the food into suitable forms for use in the body. It is greatest when protein foods are eaten.

EFFECT OF SLEEP ON PRODUCTION OF HEAT. —The production of heat is decreased 10 to 15 percent below the basal level during quiet sleep. One scientist has suggested that the metabolic rate as measured during quiet sleep should have been termed "basal metabolism," since this is the lowest rate it is possible to obtain in the normal individual. The decreased production of heat during sleep is one reason why sleep should be avoided when one is exposed to a cold environment: freezing and death will occur more rapidly than they would if the person were awake.

OTHER LESS IMPORTANT MODES OF HEAT GAIN BY THE BODY.—Some heat may be gained by the ingestion of food or drink which is hotter than body temperature, and some may be gained by radiation from hot objects outside the body. Under ordinary circumstances, these are of minor importance as compared with metabolism. However, heat absorbed by the body when it is exposed to the sun's rays on a hot summer day may be as much as two or three times the basal rate of production of heat.

LOSS OF HEAT AND PHYSICAL REGULATION OF BODY TEMPERATURE.—Since loss of heat from the body is dependent almost entirely on physical factors, it is spoken of as the "physical regulation of body temperature."

Radiation, Convection, and Conduction.—Loss of heat by radiation is dependent on the difference in temperature between the surface of the body and surrounding objects. In hot weather or when surrounding objects are above body temperature, the body will gain rather than lose heat by radiation. Loss of heat by radiation can be diminished by the use of clothing.

Loss of heat by convection is dependent on the difference in temperature between the surface of the body and the surrounding air and on the rate of movement of the air over the surface of the body. This mode of heat loss also can be decreased by the use of clothing.

Loss of heat by conduction plays only a small part in the regulation of body temperature.

1. Evaporation.—From the respiratory tract.—The air we breathe usually is relatively dry when it is inhaled, but it becomes saturated with water vapor at body temperatures while it is in the lungs and is thus laden with moisture when exhaled. For every gram of water thus evaporated the body loses about 535 calories of heat.

2. From the surface of the skin.—First is insensible perspiration. This represents water lost from the skin by the diffusion of water vapor through the epidermis (the outermost layer of skin; the one we see). It is a

loss which is entirely independent of the sweat glands and remains fairly constant under a wide variety of environmental and physiologic conditions.

Second is sensible perspiration or sweating. This water is brought to the surface of the skin by the activity of the sweat glands, and in terms of total loss of heat may represent no loss at all when the body is cold and sweat glands are inactive; or it may represent 95 to 98 per cent of the total loss of heat on a hot day when the environmental temperature is 95 degrees F or more.

3. Loss of heat due to warming of inhaled air.—Exhaled air has a temperature a few degrees less than that of the body. The heat loss due to warming of this air is dependent on the temperature of the air when it is inhaled. If air at 70 degrees F is inhaled, warming of this air will account for about 2 to 3 per cent of the total loss of heat. If air at —40 degrees F is inhaled, heat lost in this way will amount to 10 or 15 percent of the total loss of heat.

4. Other modes of loss of heat.—Loss of heat due to the ingestion of cold food or drink and its subsequent excretion at body temperature may be included in this category.

Regulation of Body Temperature.—Man is able to maintain a relatively constant body temperature of approximately 98.6 degrees F under a wide variety of environmental conditions. He does this by balancing his production of heat and his loss of heat in such manner that the temperature of the *internal* part of his body remains as close as possible to the above value (98.6 degrees F). This is accomplished by the heat regulatory center in the brain, which is very sensitive to variations in body temperature and it serves to control the aforementioned various physiologic mechanisms which produce alterations in the gain of heat and the loss of heat.

The Importance of Protective Clothing For Flyers

From a practical viewpoint the regulation of heat over a wide range of temperature can be divided into two major zones. The upper zone is marked by the importance of evaporation (that is, sensible perspiration) as the temperature regulative mechanism of the body. The lower zone is one in which the large thermal capacity of the body as well as its shivering reflex are its major protective methods. The dividing line between these two zones is the critical temperature at which regulation by sensible perspiration begins. For the nude body this critical temperature lies in the range 86 to 88 degrees F. This critical temperature naturally lowers according to the amount and thickness of clothing one wears. With an olive drab shirt and trousers this critical temperature lies at 78 degrees F. For winter flying clothing the critical temperature is 60 degrees F. For all these temperatures the subject is assumed to be in a sitting-resting position, such as he would assume inside an airplane. It is obvious that any degree of exercise would lower this critical point even further than the values indicated. The loss of heat by evaporation from the body always increases linearly with increasing temperature. The rate of increase with temperature, however, depends on the degree of clothing worn. For example, with the summer flying suit worn over an ordinary olive drab blouse and trousers a person would begin to sweat at 70 degrees F and at about 105 degrees F he would become fairly uncomfortable within a relatively short time. With the winter flying suit being worn at a temperature of 60 degrees F sweating has barely begun, but at only 70 degrees F conditions would be intolerable after a few minutes of exposure.

It is extremely important for the flyer who must wear clothing inside a warm airplane preparatory to taking off to know roughly the critical temperatures at which sweating begins and under what environmental conditions he should reduce exercise to a minimum. When one must fly from a warm environment to a cold environment, the presence of heavy perspiration soaked in clothing is extremely dangerous, because the perspiration will freeze and, as ice, will reduce the insulative qualities of the clothing very greatly.

On the other hand, for tolerance of extreme heat, clothing may serve to a very definite advantage. Just as we use clothing to protect the body from the cold, we can also use it to protect the body from radiant heat. Clothed, a person can tolerate far warmer temperatures in the desert sun than he could unclothed, provided of course the humidity is kept low.

In the presence of relatively high humidities the range of upper temperature within which the body can exercise its regulative functions is sharply reduced. Because of the low evaporating power of the surrounding air, perspiration from the body accumulates on the surface of the skin. Once the surface of the skin is wet all over, the body has reached the maximal limit of its regulative ability in respect to sensible perspiration.

In cold environments the essential problem is to conserve all heat produced by the body. Under these conditions the secretion of sweat is stopped entirely, and loss of heat by evaporation is confined only to (1)

whatever moisture diffuses through the skin and (2) the evaporation taking place inside the lungs. As a primary protective device against the cold the body may restrict the flow of blood through its periphery. This is called "vaso-constriction." Heat is transported from the interior of the body to the skin for the most part by the circulation of the blood. However, as a protective method, the body reduces its peripheral circulation when it is exposed to cold and effectively makes the outer skin of the body an insulator. It has been shown by the results of laboratory experiments that complete vaso-constriction is the equivalent of the wearing of a light wool sweater or a set of woolen underwear, as far as its insulative power for conserving heat goes.

In addition to vasoconstriction, the body has one other inherent protection against cold. Since the human body is about 65 percent water, it has very large thermal capacity. It could cool at a rate equal in magnitude to its basic rate of heat production for two or three hours without the flyer's suffering any serious reduction in efficiency. However, rather than to depend on the thermal capacity of the body for temporary protection against the cold, we must resort to various types of flying clothing.

The use of flying clothing means essentially that a thermal resistance is imposed along the temperature gradient from the internal high body temperature of 98.6 degrees F to the environmental temperature. Since, when the aviator is seated, as he is in the airplane the production of heat in the body is minimal, the requirements for clothing will be the severest. Wearing summer flying clothing, the flyer can remain comfortable inside an airplane indefinitely when the cabin temperature is maintained at 70 degrees F. At 60 degrees conditions will be comfortable only so long as the thermal capacity of the body allows. When the winter flying suit is worn, comfort can be maintained indefinitely in the sitting position at a temperature of 30 degrees F. However, this same assembly is effective at considerably lower temperatures, but a time limit in relation to its effectiveness always exists. This time limit, of course, varies much from person to person, depending on the efficiency of the circulatory system in the hands and feet.

Under conditions of extreme cold, say at −40 degrees F, it is usually either the hands or the feet which cause the first serious discomfort and possibly impair the final efficiency of the pilot. People who tolerate cold well are found to have excellent circulation in their hands and feet. People who have poor circulation in their hands and feet probably will suffer from the cold regardless of the amount of wool socks and gloves or sweaters they wear under their flying clothing. In general, the best policy in protecting the hands and feet against extreme cold is to avoid tight-fitting gloves and shoes. If gloves are used in extremely cold climates, the flyer should keep his fingers and thumb in contact with each other, except when it is necessary to pull the hand out for a delicate manipulation. Silk inner gloves, worn inside a mitten outer glove, have been found effective. For protection of the feet the standard issue item is the heavy winter flying boot. Greater protection can be obtained with this boot if one wears two or three pairs of wool socks and an inner sole instead of ordinary oxford shoes.

The final solution for the protection against cold of a flyer in an airplane ultimately will depend on how far the heating and ventilating engineer is able to progress. At altitudes of less than 30,000 feet, heating systems in modern military planes are considered to be reasonably reliable. Extreme cold, of course, always will be encountered in the exposed turrets and uninsulated waists of the bomber type of airplane. In general, heat, of course, will be ineffective if it is necessary to open side ports to fire guns or to make photographic observations.

Proper heating of the airplane obviously is the ideal solution to the problem of clothing. At present, spatial tolerances in airplanes are at a minimum. This is especially true in the case of turrets, in which the problem arises of choosing gunners who are small enough to fit in these turrets. Since turrets are extremely exposed, the insulation requirements and hence the thickness of clothing of the men who are to occupy them will be the greatest. Under these circumstances we have really three spatial factors, all working against each other, with the final solution always a compromise of two factors in favor of one. Therefore, it is clear that if airplanes are properly heated, the crew member of a military airplane will have much greater flexibility of motion with which to carry on his task and to adapt himself to the limited spatial features of the ship imposed by its aerodynamic requirements.

Bulkiness also can be avoided by the use of electrically heated clothing. In this respect another compromise exists. If we depend entirely on electrically heated clothing and not at all on insulation, we may gain extreme flexibility both in the turret and in the airplane, but by such a course the consumption of electric current will increase to the order of magnitude of 300 to 350 watts. An increase in the amount of outside clothing correspondingly decreases the current consumption. The generator supply in the airplane and

other more important demands of radio equipment and power operation of turrets will fix the surplus power available for electrical heating of clothing at a maximum. The practical maximum now is not more than 150 watts per suit. At present, electrically heated clothing is required mainly for the gunner. Heating conditions in other compartments of the ship allow crew members in those situations to wear regular flying clothing. The design of a proper electrically heated suit, which will protect the pilot at —40 degrees F, and which will use only 150 watts, will require a minimal insulative characteristic built into the outer suit about double that of the olive drab blouse and trousers.

Electrically heated suits have certain inherent disadvantages. In case of power failure, the present electrically heated suit issued by the Army would protect a seated gunner at a temperature of 0 degrees F for only approximately a half hour. The second disadvantage is its inadequate protection in case of forced landing or abandonment of the ship in a cold terrain. It is extremely dangerous to wear an electrically heated suit over Arctic terrain under any circumstances. If tactical considerations require its use, inclusion of a heavy flying clothing kit packed away in an unused portion of the ship is almost essential. Even in this case the pilot has no protection in case of a parachute descent. Our present electrically heated clothing has its best tactical use in flights over moderate or tropical temperature climate zones. Under these conditions a forced landing would not be serious.

CHAPTER XI

AIR TRANSPORTATION OF THE SICK AND WOUNDED

In the Army Air Forces the transportation of patients by airplane is assuming greater importance daily. This is evidenced by the fact that every cargo airplane now being constructed is equipped with the necessary litter fittings and brackets, so that it can be converted quickly from a cargo airplane to an ambulance airplane and, at the end of an ambulance mission, can be converted again to a cargo airplane. The following cargo and troop transport airplanes are equipped to carry from eighteen to forty patients: C-60A, C-47, C-54A, C-62, C-76, C-46, C-69, C-74, C-87, and C-93. In figure 28 is illustrated the litter installation of the C-47. When such airplanes are available, transportation by air of the sick and wounded is the method of choice. In all probability, in the present war, airplanes will not be available in any great number for assignment as ambulances; by necessity, in most instances aerial evacuation of injured soldiers will have to be accomplished by the use of aerial cargo and troop transports. In present-day warfare it is necessary to think more in terms of time than in terms of distance in connection with the evacuation of patients.

ADVANTAGES.—The advantages of the transportation of the wounded by airplane follow.

Speed.—It provides unusual speed and short duration of the evacuation process from the forward zone; that is, the evacuation of battle casualties, the evacuation from fixed installations of such areas as the Caribbean and Northwest Command, and the transportation of patients from the scene of an accident to an air field nearest a hospital in which treatment may be given. An example of the latter is the transportation of patients from outlying fields or scenes of accidents as is practiced at our Air Force training schools. Unusual speed and short duration of evacuation from any zone are insured.

Comfort.—Comfort in transit, instead of a rough and long ride in a motor or train ambulance, is assured.

Safety.—Safety is well provided for.

Economy of Workers.—The conservation of medical personnel and field equipment is obvious.

Care.—Patients receive constant observation and care during flight by trained enlisted, nursing or flight surgeon personnel.

Earlier Treatment.—More adequate treatment for the badly injured and seriously ill is obtained by the materially shortened period needed to bring them to their ultimate destination where definitive treatment can be given. Thereby, the patient's chances for recovery are improved. This is especially important if a major surgical procedure to be done by highly trained specialists is necessary.

Figure 28—Cabin of the C-47, showing the litters in place. See chapter 8 for use of the litter straps seen here.

Reduced Land Traffic.—Congestion on the land lines of communication is reduced.

Heightened Morale.—The morale of wounded soldiers is much improved when they know that such service is available.

General.—Patients who have burns of the face and hands, injuries to the eyes, wounds of the joints, gunshot fractures and wounds of the lungs are particularly benefited by airplane evacuation to surgical centers where the best personnel in diagnostic and therapeutic procedures are available.

DISADVANTAGES.—The disadvantages of airplane ambulances follow.

Fields and Service.—Reasonably good landing fields and servicing facilities are always required.

Weather Limitations.—Usefulness is lost or reduced during adverse weather.

Attack by Enemy.—The danger of attack by hostile aircraft is always present, and yet any other type of evacuation runs similar risks and over a longer period.

UTILIZATION OF REGULAR FIELDS.—In many instances, such airplanes could be flown and serviced from regular Army Air Forces fields, especially when it is remembered that these airplanes are actually cargo and troop transport airplanes which must require such service. Very bad weather would force cancellation of flights. Night flights also could be made.

CARE OF PATIENTS IN AIRPLANES.—As explained in chapter III, anoxemia normally causes an appreciable handicap at altitudes of from 10,000 to 11,000 feet. Any clinical condition such as pneumonia or damage to lungs caused by gas will be less well borne at high altitudes than at sea level, but such anoxemia usually can be controlled by the administration of oxygen. Injuries to the head cause a depression of the oxygen saturation of the arterial blood, so that any patient who has a clinical condition, such as an injury to the head, that causes anoxemia may require oxygen at ground level. In this group would be included patients who have lost much blood as the result of wounds and patients who are in a state of severe shock or who have had severe and sudden infections.

The hazards of aerial transportation to patients who have a collection of gas between the chest wall and the lung (called "pneumothorax") occur because the volume of air (saturated with water vapor at 37 degrees C or 98.6 degrees F) in a pneumothorax increases with altitude according to Boyle's law, as illustrated in the X-ray in figure 29. This is the reason that the airplane ambulance kits contain a syringe and needle with which excess air can be removed from the chests of patients who have such conditions. As in the case of air in a pneumothorax, gas normally present in the gastro-intestinal tract will expand with altitude (figures 19*a* and *b*). This may result in expansion of the stomach and intestines and possible tearing of tissue which has been recently sewn, or the forcing of gas out through any openings in the intestines and the carrying of fecal material into the peritoneal cavity. This is the reason that patients who have intestinal obstruction, perforating wounds of the intestine, strangulated hernias and perforating ulcers of the stomach should be transported only when it is possible to fly at very low altitudes, unless the tactical situation demands that they be evacuated. When evacuation of this type of patient is necessary, a stomach tube, which is carried in the airplane ambulance kit, should be inserted in the patient's stomach so that any excess amount of gas will be expelled through the tube during flight. If possible, the patient also should be given an enema before take-off and a rectal tube should be inserted at fairly frequent intervals if an altitude in excess of 2,000 to 3,000 feet is attained.

Patients who have severe heart disease or severe symptoms of poisoning by the sulfonamide group of drugs should receive unusually careful attention during flight and should be given oxygen continuously. Provision is made in the airplane ambulances so that the majority of the litters can be tilted at an angle of 15 or 20 degrees. This provision will be of value, since it is well known that patients who have injuries of the head, neck and chest should be transported in the head-up position, whereas patients in a state of shock should be transported in the head-down position. All patients should be retained in place on the litters by litter straps (figure 28).

According to present plans, all aerial transportation of the sick and wounded will be carried out by Air Evacuation Groups (Medical) attached to the Army Air Forces. These groups will be responsible for loading the patients on the airplane, transporting them to their destination and unloading them there. The groups will be trained in the care of the sick and wounded during flight at a special school, and will be thoroughly acquainted with the installation of litters in cargo airplanes and the use of all the items in the airplane ambulance kit.

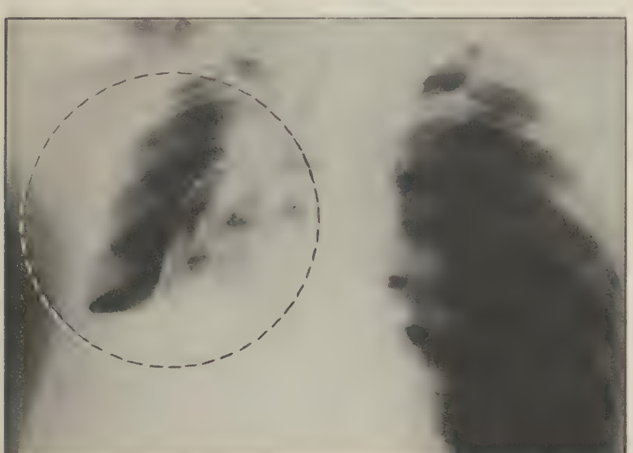


Figure 29a.—Pneumothorax at ground level.

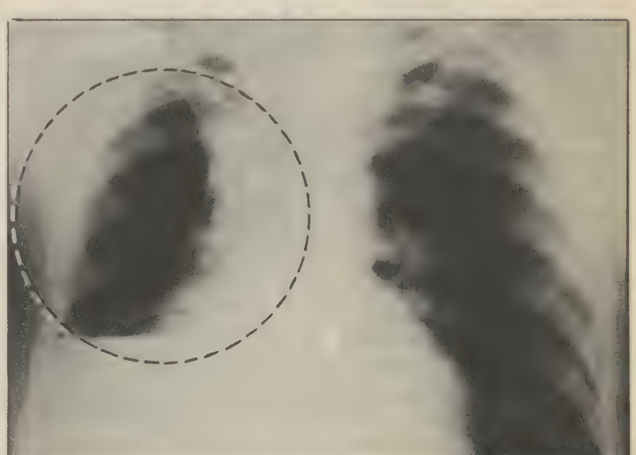


Figure 29b.—Pneumothorax at an altitude of 10,000 feet.

CHAPTER XII

PARACHUTE ESCAPE AT HIGH ALTITUDES

INTRODUCTION.—Many things happen to an airplane flying at great altitudes in wartime which compel the flyer to abandon his plane. Fire, crumpled wing or severe damage inflicted by enemy gunfire cause an immediate necessity for bailing out, without time for diving the airplane to lower altitudes. The latter procedure is not always feasible, since structural strain may collapse the aircraft, causing the pilot to lose control and thus adding to the difficulty of his escape.

With nonpressurized aircraft, approximately 40,000 feet is the limiting altitude. In the rarefied air of this altitude, descent will be rapid and it is highly probable that considerable altitude would be lost before escape from the aircraft could be effected. In the case of pressurized aircraft, which eventually may attain heights of 50,000 feet, it is entirely possible that escape might be made from altitudes approximating 40,000 feet or slightly more.

THE BAIL-OUT BOTTLE.—A small oxygen cylinder has been designed and made available to high-altitude flyers for use in bailing out. This bottle is designed to be carried in a pocket of the flying suit, and the oxygen is supplied through a pipestem. An eight-minute supply of oxygen is available; it is enough to permit safe descent from any altitude in an open parachute without loss of consciousness. To use this bail-out bottle the oxygen mask must be removed and the pipestem placed between the teeth. The protection from the extreme cold afforded by the mask is thus lost, and the flyer's face is exposed to possible freezing during the descent through the upper atmosphere.

THE WALK-AROUND BOTTLE.—In a multiplace aircraft, such as a bomber, the walk-around bottle as well as the bail-out bottle usually is available. Since the walk-around bottle can be used without removal of the mask, it is in some ways superior to the bail-out bottle in case of emergency. It could, at least, be employed up to the point of clearing the airplane. Flyers should decide for themselves the technic of escape best suited to the prevailing conditions and rehearse this procedure repeatedly until it can be carried out smoothly. The laboratory tests about to be described should serve as a guide to the intelligent flyer who wishes to provide against the day when he may be forced to escape from an airplane at an extreme altitude and through hostile aircraft gunfire.

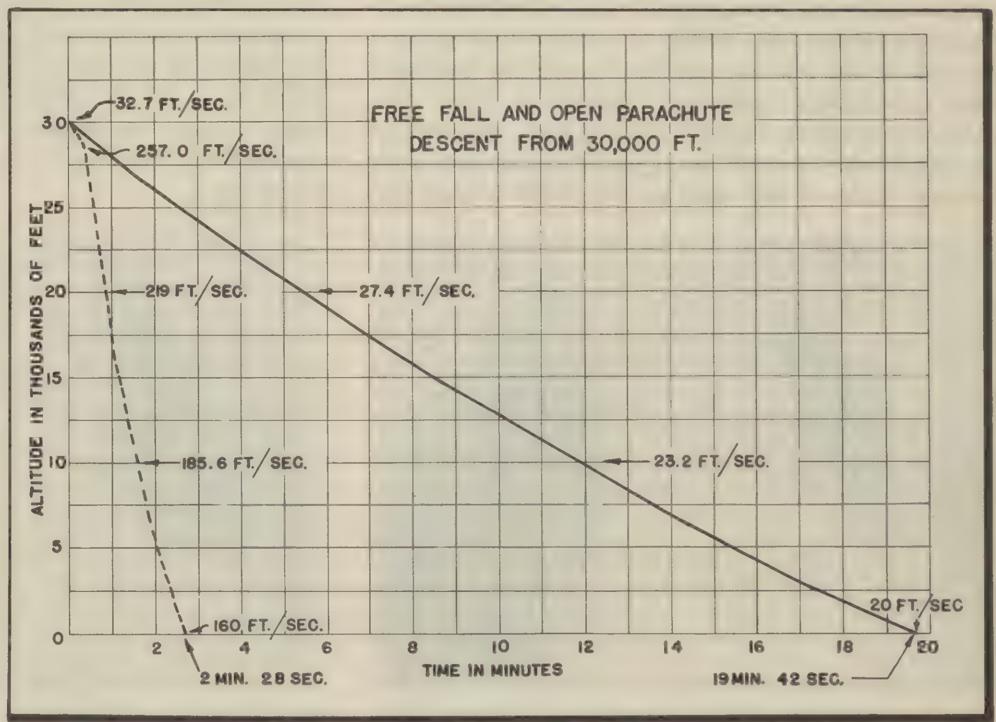


Figure 30 — The dotted line represents the speed at which a man falling without a parachute would reach the earth from an altitude of 30,000 feet. The solid line represents the time in which a man with a parachute, descending from the same height, would reach the earth. Note the changes in the rate of speed in each case. Note that if a flyer "falls free," without opening his parachute, until he reaches lower altitudes, he will quickly escape the extreme cold and lowered oxygen tension of the high altitudes.

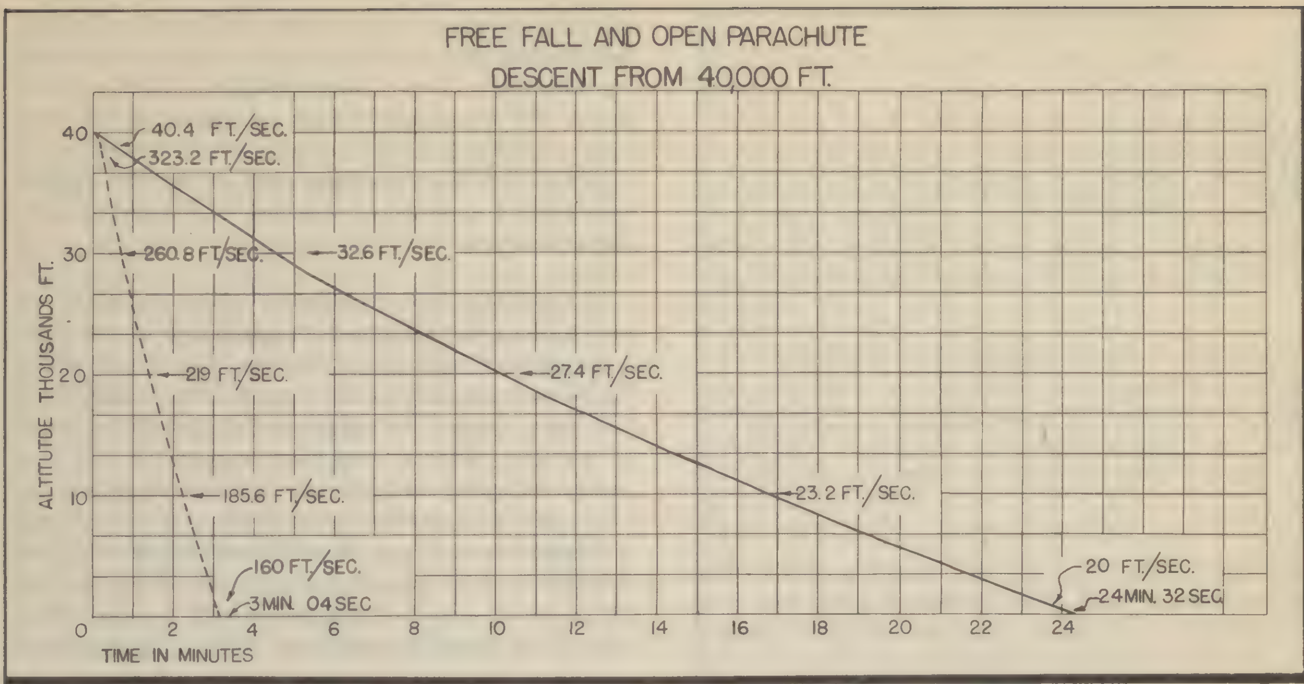


Figure 31—This figure shows that if a man "fell free" from an altitude of 40,000 feet, he would reach the earth in slightly more than three minutes, whereas if he "fell free" from 30,000 feet (figure 30) he would reach the earth in two minutes, twenty-eight seconds. Compare this figure with figure 30 for comparative times of descent from 30,000 feet and 40,000 feet, with a parachute.

ADVANTAGES OF FREE-FALL DESCENT.—The time for both free-fall and open parachute descent from 30,000 feet of a man with parachute pack attached is shown graphically in figure 30. The same data concerning descent from 40,000 feet are shown graphically in figure 31. It is readily seen that a flyer's exposure to the low oxygen tensions and extreme cold of the higher altitudes will be short if the free fall is employed until lower altitudes are reached. Also of practical importance in military aviation is the fact that a free falling body presents less of a target for enemy gunfire. Recent war experiences prove that the latter fact no longer is an academic consideration.

Another argument for free fall is the fact that men sometimes are lost because the rip cord is pulled too soon and the parachute is fouled by the airplane. Also, in high-speed airplanes, the velocity of the man immediately after escape is so great that if the parachute is opened too soon, the terrific strain on the shrouds of the parachute may tear them loose. It has been advocated that when possible, single-place airplanes be pulled almost to a stall before the aviators leave them. In any case, the flyer should delay opening his parachute until he has slowed down, in order to avoid the possibility of injury to himself and the parachute.

Simulated free-fall parachute descents in the low-pressure chamber have shown that descent from an altitude of 40,000 feet can be carried out without loss of consciousness and without any supplementary oxygen equipment, provided that a deep breath of oxygen is taken prior to the start of descent and the breath is then held for as long as thirty seconds. If the latter two conditions are not employed, a brief span of unconsciousness will ensue. Even if a period of unconsciousness is experienced it will be very short, and, except in the case of an injured man, it seems almost certain that recovery will be made in plenty of time to allow for opening the parachute. It is doubtful that the man would even know he had been unconscious because of lack of oxygen. In a series of laboratory tests in which the condition of loss of consciousness at altitudes of from 30,000 to 36,000 feet was simulated, the subjects "fell free" and all recovered sufficient consciousness to pull the rip cord between 2,200 and 25,000 feet, the average pull being made at 14,100 feet.

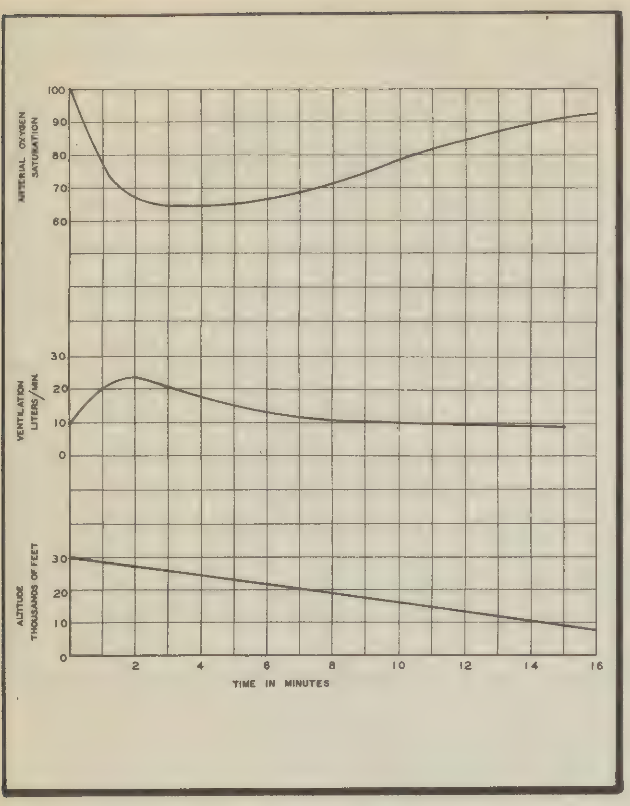


Figure 32—Percentage of saturation of arterial blood with oxygen, and ventilation rate, compiled from data concerning thirteen subjects who made simulated descents by open parachute from an altitude of 30,000 feet, in a low-pressure chamber. See also the section on respiration in chapter 3.

The effect of free fall on the ears is great and rupture of the eardrums may occur unless the parachutist is able easily and readily to clear the ears. But if free fall is employed only in the higher altitudes and is stopped by opening of the parachute at about 15,000 feet, the danger of rupture is not so great. Although they are painful and temporarily incapacitating as far as flying is concerned, ruptured eardrums cannot be given too much consideration in a discussion of emergency parachute escape.

DESCENT BY OPEN PARACHUTE.—If the parachute were opened at an altitude much above 35,000 feet and the flyer were without oxygen, he undoubtedly would suffer severe and possibly fatal anoxia. If, on the other hand, the flyer is not at an altitude of more than 30,000 feet, he may open the parachute immediately and be assured of a safe descent without loss of consciousness, without the use of oxygen. In figure 30 are shown altitude-time relationships during descent by open parachute from 30,000 feet, and in figure 31 similar relationships are shown in a descent from 40,000 feet. In figure 32 is shown the average saturation of arterial blood with oxygen (Refer to section on respiration, in chapter 3.) together with the ventilation rates of thirteen subjects who performed simulated descents from 30,000 feet by open parachute in the low-pressure chamber.

CLEARING THE AIRPLANE.—The foregoing results indicate that the greatest hazard in parachute escape is involved in clearing the airplane. The time available depends on the state of the airplane, the availability of emergency oxygen, the altitude and the presence of mind of the flyer. Without emergency oxygen, he will have periods of useful consciousness of from one to one and a half minutes at 30,000 feet; about thirty to forty seconds at 35,000 feet and only about fifteen seconds at 40,000 feet. After these periods have expired escape will be impossible because consciousness will be lost. These periods of useful consciousness will be shortened in case of injury or severe physical activity.

SUMMARY.—Provided the oxygen supply of the plane is abandoned just before escape, either free fall or open-parachute descent can be effected from an altitude of 35,000 feet or less without the use of supplementary oxygen. For altitudes of from 35,000 feet to 40,000 feet, if the flyer will take a deep breath of oxygen, then hold his breath and "fall free" he will descend to safe levels without loss of consciousness and without the use of emergency oxygen equipment. In the latter case, the eardrums may be ruptured, but only one of twenty-eight men who have attempted this rate of descent in the low-pressure chamber has been unable to clear his ears.

In leaving a high-speed airplane, the flyer may experience difficulty in getting out, and the speed imparted to the falling body may place undue strain on the parachute shrouds if the parachute is opened too soon. A free fall is recommended until the velocity imparted by the airplane is diminished. Near-stalling of the airplane before the flyer leaves it in the case of a fighter airplane, will remove this danger. The time involved in getting out of the airplane is important if it is done without oxygen equipment.

Following is a story told by one Army fighter pilot, a member of the Caterpillar Club, about his emergency escape:

"My plane was in a spin from which I could not pull out. I decided I would abandon the plane and to do so would crawl out the wing so as to be thrown clear of

the plane. I got just a few feet out on the wing and slipped and fell off. Seconds later some portion of the plane—I don't know which part—hit me. In this collision one side of my head was hit hard, with some hair and skin being removed; a considerable portion of skin was removed from my back; and I received a blow on the lower jaw. My immediate thoughts were that I might pass out and that perhaps I should pull my rip cord at once. I was at this time facing the ground and had just estimated my altitude at about 3,000 feet. The plane was still just above and to one side of me, so I decided to not open up but to take a chance on reviving before hitting the ground. It is obvious that I did revive and when I did so I found myself facing upwards with the airplane still just above me. Looking over my shoulder, I estimated my altitude at 1,200 feet.

"I decided to check on my parachute and felt for it but it wasn't there! My reaction was more one of disgust than fright. Soon I discovered my 'chute down at my feet where it had been knocked by the previous impact of the plane.

"The plane was still overhead, and the ground was only about 600 feet away when I finally decided I had only one chance left.

"For years I had disciplined myself in the resolve not to pull the ripcord too soon in the event of an emergency jump: the danger of fouling the 'chute on the plane had been impressed on me. I was thinking of this throughout the descent.

"At 600 feet I pulled the ripcord. The parachute responded immediately and in opening bounced off the wing of the plane. The 'chute had been ripped and torn somewhat in the mid-air collision, so the descent was somewhat rapid. I lit hard, but was only shaken up and not hurt.

"This was my second jump and first emergency. The first jump was a practice one some years before."

CHAPTER XIII

OXYGEN IN AVIATION

INTRODUCTION.—The use of oxygen in aviation has raised the absolute ceiling, physiologically speaking, from 18,000 to 44,000 feet. It has also placed a heavy responsibility on those officers who are responsible for teaching flyers the narrowness of the divide between life and death at extreme altitudes. Physiologically, one can be at his best up to an altitude of 37,000 feet when provided with perfectly functioning oxygen equipment. Loss of one's oxygen at an altitude of 37,000 feet means loss of consciousness within thirty seconds and death not long thereafter. Flyers must be disciplined in the use of oxygen equipment as carefully as ground personnel are disciplined in the use of gas masks. To illustrate the point, three experiences follow. The first two of these are quoted from a translation of a German manual published in 1939. These stories doubtless have been impressed on flyers in the German Air Force. The third experience is a first-hand account supplied by a pilot of the Army Air Forces who came to the Materiel Center for special instructions in high-altitude flight.

PREWAR EXPERIENCE IN THE GERMAN AIR FORCE.—"A plane fell from a great height. Out of the crew of four, three were fatally injured and the pilot escaped by parachute. The investigation of the crash revealed the following facts: The flight was undertaken without oxygen masks, oxygen being provided only by pipe stem (figure 34). None of the crew had his nose clamped, and none was strapped in place. According to the pilot, the ascent had reached 21,000 feet when the climb suddenly ceased and he lost consciousness. Since the barograph actually showed an altitude of 24,500 feet, it is to be assumed that the pilot was not competent to judge the altitude because of beginning anoxia until he suddenly lost consciousness at 24,500 feet. Consciousness returned to the pilot at about 3,000 feet. He had been thrown out of the plane. According to his own story, he had interrupted his oxygen supply and had conversed with the copilot shortly before losing consciousness.

"The cause of the onset of altitude sickness in this case is to be ascribed to simultaneous breathing through

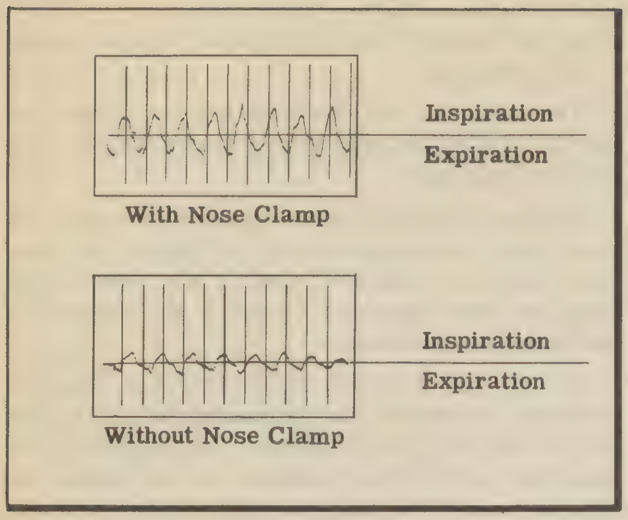


Figure 33—Tracings of the rate of respiration, subject breathing through a pipestem in the mouth. Notice what happens when the nose is not clamped shut tightly.

the mouth and the nose. Upon suddenly losing consciousness, the pilot fell forward on the controls so that it was not possible for the copilot to manage the plane. The machine rapidly lost speed and fell. The pilot was thrown out of the cockpit and was thereby saved.

"This accident showed how important it is that *pilots be required to use oxygen apparatus which has undergone thorough physiological trial and that they be fully instructed in the physiological action of altitude.** The failure to close the nose in the accident described above while using the pipestem method of breathing oxygen suggests that the pilot was unaware that under these circumstances he took in considerably rarefied air through his nose. Figure 33 shows two respiratory tracings, one recorded with the nose closed and one with it open. Both were recorded through the mouth and show that even with the best intent it is not possible to breathe through the mouth exclusively. A further mistake on the part of the pilot was to interrupt the oxygen supply completely while he conversed with his companion. The collapse was immediately due to this relatively brief diminution in the oxygen supply."

EXPERIENCES OF BRITISH FLYERS OPERATING WITHOUT OXYGEN IN WORLD WAR I.—"The effect of altitude on all these processes of consciousness may be illustrated by a number of examples taken from the last war. Thus, in one of the reports of the British War Ministry the following record by a medical staff officer of the British Air Corps is to be found: 'An English pilot in a Bristol fighter plane encountered a formation of five German planes at an altitude of 6,000 meters (20,000 feet). He did not recognize the danger, but waved to them in spite of the protests of his observer.' Here we have an extraordinary change in the power of judgment if, as is evident from the report, a person no longer recognizes the danger by which he is threatened. We hear, furthermore, of cases of absent-mindedness. Thus, an English observer while photographing forgot to change his plates and took eighteen pictures on one plate. A number of similar examples could be mentioned from the war literature. They all prove under what difficult circumstances our wartime aviators had to fight. We cannot fully appreciate their heroic deeds unless we consider also the physiological difficulties with which they were faced at these altitudes. For the aviators, in addition to the visible enemy, had to fight against an invisible foe—the want of oxygen."

*The italics are ours. This statement is emphasized because the early adoption of this policy certainly has much to do with the success of the German Air Force.

EXPERIENCE OF AN ARMY AIR FORCE CREW IN A TRAINING FLIGHT AT 35,000 FEET.—"One day in April, 1942, while on a high altitude mission at Geiger Field, one crew went up to 35,000 feet in a B-17E. The pilot, in checking the members of the crew at this altitude, was unable to contact the radio operator. He sent the engineer to see if he was all right. The engineer took several deep breaths of oxygen (there being no portable equipment) and went back through the bomb bay to the radio compartment where he attached his mask to an extra outlet. He woke the radio operator, who was asleep, and put him on interphone and started back for the pilot's compartment. He collapsed on the bomb bay catwalk and fell onto the bomb doors. The pilot saw him and went to his assistance and collapsed under the turret before reaching him. The radio operator, with the help of the assistant radio operator, in the meantime, had jerked the engineer up onto the catwalk. The two of them nearly collapsed as a result of this exertion but soon recovered and got the engineer and pilot to oxygen where they, too, recovered. The A-8 type masks were used."

Oxygen Equipment

The physiologic necessity for a supplementary supply of oxygen above certain altitudes has been shown in the preceding pages. The percentage of oxygen required in the air breathed to maintain satisfactory oxygen saturation of arterial blood can be calculated. The problem of furnishing oxygen to flying personnel then becomes essentially an engineering one.

TWO ESSENTIAL REQUIREMENTS OF A GOOD OXYGEN SYSTEM.—These are: (1) economy in weight and (2) safety and reliability under the adverse conditions encountered in combat operation. The equipment should function satisfactorily under great extremes of temperature, pressure, acceleration and movement of air. Furthermore, various rates of oxygen supply must be available which will economically satisfy man's needs, not only through varying altitudes, but also through periods of high oxygen consumption such as result from bouts of exercise or, in extreme cold, from shivering.

LIQUID OXYGEN.—Among the earliest methods of dispensing oxygen at high altitudes was the use of liquid oxygen equipment. Very early, however, the use of liquid oxygen had to be abandoned in military aviation, due to the impracticability of storing large quantities of liquid oxygen for use at unpredictable moments. Liquid oxygen boils away continually and, as such, cannot be stored in the same manner in which the compressed gas can be stored.

Figure 34—Free-flow type of oxygen system, with type A-6 regulator.

CONTINUOUS-FLOW OXYGEN SYSTEM *(Figure 34)*.—Ever since the use of liquid oxygen was abandoned and up until the middle of 1939, the complete oxygen equipment consisted essentially of:

1. High-pressure cylinders for storing the oxygen. These cylinders were lightweight aircraft cylinders in which the oxygen was stored at a pressure of about 1800 pounds per square inch.

2. High-pressure oxygen fittings and lines. These lines conveyed the high-pressure oxygen from the storage cylinders to the dispensing equipment.

3. A regulator for dispensing a metered quantity of oxygen to flyers at altitude. The regulator was the Type A-6 and was manually controlled.

4. A low-pressure flexible rubber hose for conveying the oxygen from the regulator directly to the flyer.

All the above equipment has serious shortcomings. These deficiencies and the manner in which they were remedied will be considered in the following paragraphs.

DEFICIENCIES OF THE PIPESTEM.—The low-pressure flexible hose which conveyed the oxygen from the regulator to the flyer is commonly known as the "pipestem." The pipestem is nothing more than a rubber tube held in the mouth between the teeth. This method of administering oxygen is extremely unsatisfactory, as the German account of its failure indicated.

In the first place, when this system was used, oxygen poured continually into the flyer's mouth, puffing up the cheeks and requiring that the mouth be held open, to allow excess oxygen to escape. Some pilots would "bite off" the oxygen. This consisted essentially of closing the teeth on the pipestem at the end of every inhalation and thus stopping the flow of oxygen during exhalation. However, this procedure was detrimental to the oxygen regulator.

In the event that the oxygen was cold, as it frequently was, the sensation caused by the oxygen pouring into the mouth out of the pipestem was very much akin to that of holding an icicle in the mouth, and as such, was rather uncomfortable. The use of the pipestem necessitated breathing by mouth. To breathe through the nose could be fatal at altitudes above 30,000 feet. Mouth breathing, of course, is undesirable, inasmuch as the normal method of breathing is through the nose or through both the nose and the mouth.

Above all, the pipestem method of administering oxygen was extremely inefficient. A large amount of oxygen was wasted, inasmuch as the body simply did

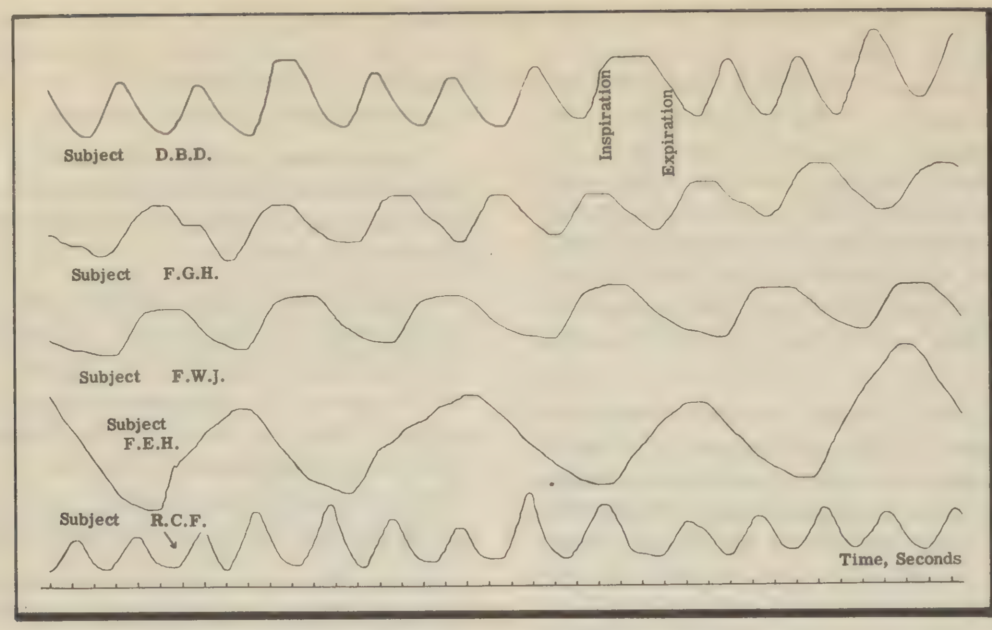


Figure 35—Records of the respiratory cycles of five young men at rest. The ascending part of the curves corresponds quantitatively to the phase of INSPIRATION; the horizontal or near-horizontal part of the curves to the pause phase; and the declining part of the curves to the phase of expiration.

not use it. That part of the respiratory cycle during which air is being drawn into the lungs occupies less than a half of the total time required to complete the cycle. In figure 35 are shown characteristic respiratory cycles in five young men at rest. The rising portion of the curve corresponds quantitatively to the inspiratory phase; the horizontal or near-horizontal, to the pause phases; and the declining portion, to the expiratory phase. The inspiratory phase in these examples occupies from 28 to 33 percent of the total cycle, and the pause phases from 5 to 19 percent. In the continuous-flow system without reservoir bag, therefore, these five subjects under the most favorable conditions would inspire from 40 to 46 percent of the oxygen flowing from the regulator. These percentages are those delivered during the inspiratory phase and the pause immediately preceding inspiration.

Oxygen Masks

TYPE A-7 OXYGEN MASK *(Figure 36)*.—The first type of oxygen mask, the type A-7, was a nasal type mask constructed with a dipped rubber nasal cover containing two dependent rubber tubes around the wearer's mouth which terminated in a single supply tube below the chin. One of the greatest disadvantages of this mask was the danger of breathing in through the mouth. It is now obsolete.

THE TYPE A-8 OXYGEN MASK *(Figure 37)*.—This is an oronasal type of mask (fits over both nose and mouth) which also permits rebreathing part of the oxygen expired from the lungs and respiratory passages. It incorporates many improvements in design over the A-7 and was soon issued to replace it. This mask consists of a rubber molded nasal cover with a rigid case of phenolic compound which supports the mask and a turret-like protrusion containing a sponge rubber disk in front of the mouth. Attached to the base of the mask is a connector sleeve of phenolic compound to which is attached a flexible rubber rebreather bag provided with an oxygen intake tube. The end of the intake tube is equipped with an oxygen mask coupling fitting, which permits the mask apparatus to be readily attached, bayonet fashion, to the oxygen outlet. The oronasal feature and the sponge rubber disk represent the principal improvements of this type of mask over the type A-7.

The principle of the type A-8 is essentially the same as that of the type A-7, with the exception that there are no metal parts and the sponge rubber disk takes the

Figure 36—Subject wearing a type A-7 oxygen mask, connected to cylinder of oxygen.

place of the exhalation valve and the air regulating mechanism. As in the type A-7 mask, a mixture of oxygen and previously exhaled gases is inhaled from the rubber reservoir bag. Upon exhalation the first part of the expired air passes into the bag and as soon as the bag becomes distended, the remaining gases pass out through the sponge rubber disk. Upon inhalation, first the gases are taken from the bag and when the bag is depleted an additional amount of air is drawn in from the atmosphere through the sponge rubber disk. Increasing the flow of oxygen at higher altitudes permits the flyer to breathe a richer mixture of oxygen and lesser amounts of atmospheric air.

In this mask there are no portholes to manipulate and there is no danger of anoxia in the event the flyer breathes through his mouth. The valve which is the sponge rubber disk does not freeze up as readily as does the metal valve on the A-7 mask, but here again, this type of mask has several shortcomings, some of which are peculiar to it alone, and some of which are common to both types of masks.

Difficulty of Communication.—The principal difficulty is the inability to carry on interphone and radio conversation easily and distinctly. Some amount of conversation can be carried on through the sponge rubber disk, but the results are not good.

Difficulty in Use of Instruments.—Bombardiers have complained that the mask and especially the turret in front of the mouth interfere with convenient use of the bomb sight. The rebreather bag hanging down from the facepiece of the mask sometimes interferes with normal manipulation of the wearer's hands at the controls or other equipment, or the bag may become caught in other apparatus.

Danger of Freezing.—After extended use of the mask at low temperatures, the sponge rubber disk will fill with ice, thus making it impossible to exhale or inhale through it. Even before actual freezing occurs, the sponge rubber disk will gather up much moisture.

Deficiency in Support.—The method of holding the mask to the face is capable of being improved.

THE MASK TYPE A-8A *(Figure 38)*.—This mask, for the most part, is identical with the type A-8, contains just one change of importance. The inlet tube which formerly ran directly into the rubber bag and was suspended from the rubber bag is connected to the phenolic connector piece, thereby greatly relieving excessive wear and tear on the rubber bag.

Figure 37—The type A-8 oxygen mask. There are no metal parts in this mask.

Figure 38—The type A-8A oxygen mask. The inlet tube, which in previous types ran directly into the rubber bag and was suspended from the bag, is connected to the phenolic connector piece.

THE LATEST STANDARD REBREATHER TYPE OF MASK.—This is the type A-8B mask (figure 39). The function and use of this mask are essentially the same as type A-8 and A-8A. The principal differences are in the means of suspension, the incorporation of a microphone pocket and the incorporation of two sponge rubber disk turrets.

The A-8B mask is provided with a helmet suspension. Buckle tabs to be used on the helmet are furnished. Leather and elastic strapping is used in the suspension in place of the rubber straps. The mask is buckled directly to the helmet. However, an adaptor is available for use of the mask without the helmet.

The microphone is installed in the central pocket, while the two turrets, one on either side of the pocket, contain the sponge rubber disks. Two disks reduce the breathing resistance and lessen the chance of freezing.

Precautions Indicated in the Use of Continuous-flow Equipment.—When one realizes the limitations of the type A-8 mask and the continuous-flow system, and does what he can to surmount them, excellent results can be obtained with it—it has been used in flight to altitudes of 40,000 feet and in the chamber to a simulated altitude of 43,000 feet.

Important Safeguards.—Careful attention to the following safeguards will avoid many pitfalls.

Before the Take-off:

1. Check the cylinder pressure; it should show: for A-6 or A-8 regulators, 1,800 to 2,000 pounds; for A-9 or A-11 regulators, 400 to 450 pounds.

2. The valve on the high-pressure cylinder must be full open or full shut. Leakage is frequent at intermediate positions, and flow may be insufficient.*

3. Have rate of flow checked every ten days with a flowmeter, Specification No. 40400, if possible; the regulators are variable in performance.

4. Be sure the mask and the bag are securely wired to the plastic connecting tube.

5. Check bag for small holes. Be sure plug is in the bottom of the bag.

6. Make certain that exhalation disks are in proper position.

7. Know where your regulator is located.

8. Carry protective shields for the exhalation turrets, if they are available. (Dwg. 43B8375.)

9. Never apply oil to any part of the oxygen equipment.

10. See that all parts are free of dirt and properly policed.

11. Check system frequently for leaks. Pressure should maintain itself overnight with all regulators set to "OFF" position.

12. Make sure the valve adjustment knob of the regulator has a fair resistance against turning, lest a sleeve brushed against it change the setting. This resistance can be increased by tightening the gland packing nut (figure 40).

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*One source of accidents reported is failure to open completely the cylinder valve. While the regulator is closed, the slightest crack of the cylinder valve will suffice to show the cylinder pressure. Yet when the regulator is turned on, the "crack" may be insufficient to supply adequate flow, so that the pressure gage falls rapidly to a low value. It is thus important to be sure the cylinder valve is full open and to get the habit of looking down at the cylinder pressure gage after the first two or three breaths have been taken.

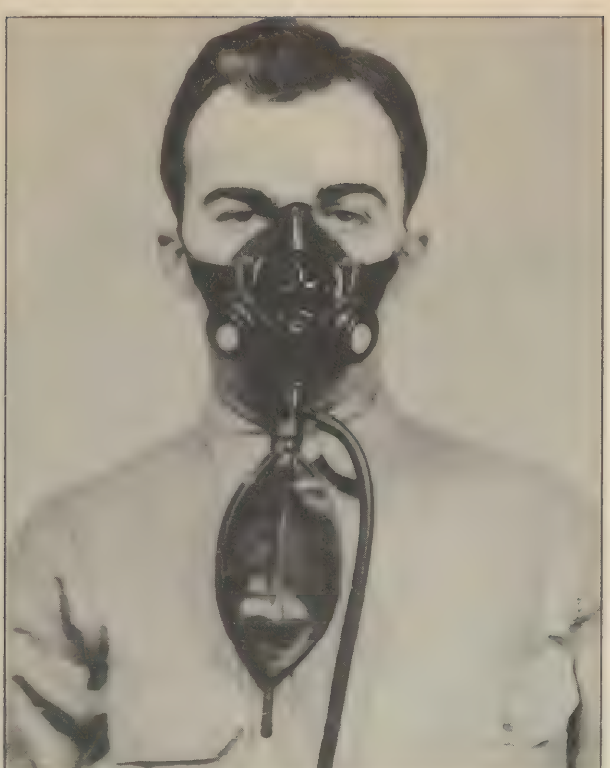


Figure 39—The type A-8B oxygen mask, the latest standard rebreather type of mask. It has a microphone pocket, is suspended differently, and has two sponge rubber disk turrets.

In the Air:

1. Be sure your regulator is set to proper altitude.

2. Check cylinder pressure occasionally.

3. Always breathe normally—voluntary overbreathing accomplishes nothing.

4. Put on protective shields when temperature falls below 10°F (–12.3°C); if not available, examine sponge at intervals, removing ice by squeezing. Carry an extra set of sponge rubber disks or, better still, an extra mask.

5. Above 30,000 feet, the bag should never be completely collapsed during inspiration; if it is, the valve should be opened further, no matter what the flowmeter reads.

6. When muscular exercise is required, adequacy of oxygen supply requires that the valve be open far enough so that inspiration does not collapse the bag at an altitude of more than 25,000 feet.

7. On change of station at altitude, be sure new cylinder valve is full on and that bayonet fitting is locked.

After the flight:

1. Shut the flow valve and be sure it is tightly closed before leaving the airplane.

2. Occasionally wash mask with soap and water, rinse well, and hang it up to dry.

3. Never expose the mask unnecessarily to heat or sun.

4. Never loan your mask to anyone except in emergency.

5. Keep your mask in its place. This place is in the ship during flight.

6. Check bayonet connection to see that small rubber seat is in place.

THE DEMAND MASK: GENERAL.—Since the demand regulator releases oxygen only in response to the suction of inspiration, the mask which is used with it must fit tightly to the face to insure an adequate oxygen supply at extreme altitudes. The mask consists of a facepiece with an expiratory valve mounted in it, a connecting tube for oxygen supply, and straps for suspending it from the helmet or a head harness. In use in the service at present are three types of demand masks: the A-9, of which only a few have been made, the A-10, which is being procured in four sizes, and a mask adapted from the type A-8 constant-flow mask. The demand system is considered more fully in another section of this chapter.

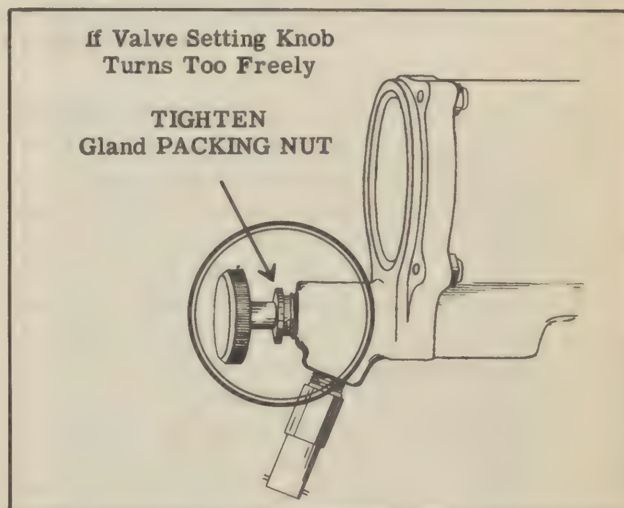


Figure 40—The valve adjustment knob of the oxygen regulator should have a fair degree of resistance against turning. If it does not, a sleeve brushed against it may change the setting. The arrow points to the gland packing nut, which can be tightened to provide the degree of resistance (of the knob) desired.

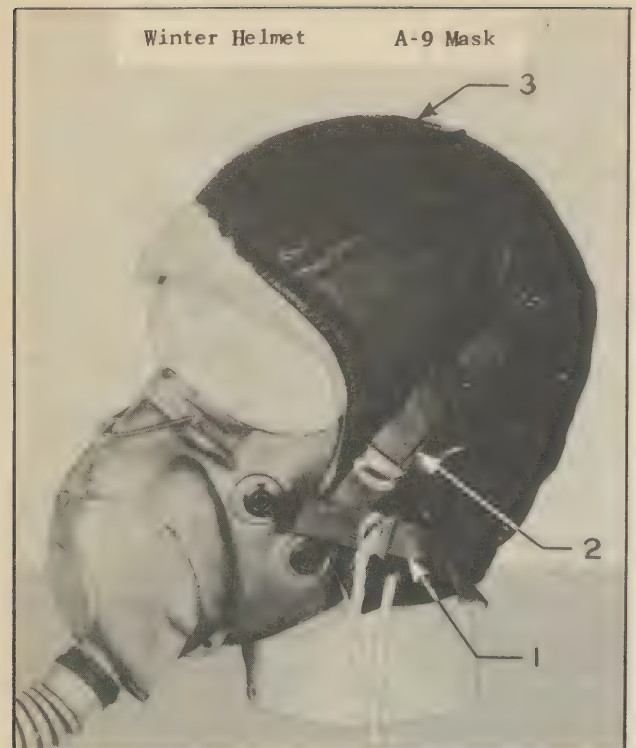


Figure 41—The type A-9 mask (Specification 3125): a, with helmet straps crossed; b, with helmet straps worn parallel.

FIRST TYPE OF MASK.—The first type of demand oxygen mask, type A-9 (figure 41*a* and *b*), fully covers face when used with helmet and goggles, and is suspended from the headstrap or helmet by four straps. These straps can be used crossed (figure 41*a*) or in a parallel manner (figure 41*b*) in attaching the mask. In figure 42*a* it is shown without the helmet and with straps crossed; in figure 42*b* it is shown without the helmet and with straps adjusted in parallel manner. Oxygen is brought through the corrugated rubber tube with each inspiration, and enters the mask through two ports alongside the nose. The expired air goes out through the rubber flutter valve and is conducted down across the face of the mask under the shield and out. This keeps warm-air insulation between the valve and the outside air, and should prevent freezing of the mask at temperatures of as low as –45°C. Should the valve or any other part freeze, the mask should be squeezed to free it from ice. The microphone (MC253 or MC254) is designed for insertion in a pocket in the nose section of the mask. *The rubber sealing plug should be in place in this pocket at all times when a microphone is not used.*

THE A-10 MASK *(Figures 43a and b)*.—This is an improved type A-9. A strap goes from the bridge of the nose to the helmet or headstrap. This is to prevent any sudden accidental tug or high *g* effects from dislodging the mask. The A-10 mask is made in four sizes: (1) extra small, (2) small, (3) standard, and (4) large. The straps used for attaching it to a head harness or to a helmet can be worn parallel (figure 43*a*) or crossed (figure 43*b*).

KIT TO CHANGE TYPE A-8B MASK TO A DEMAND TYPE.—It will be recalled that the type A-8B mask is a continuous flow type of mask. A kit has been devised to change this mask to a demand type. The conversion is accomplished be replacing the rebreather bag

and oxygen inlet tube with a corrugated tube, similar to that provided in the type A-10 mask, leading to the standard disconnect joint. Each sponge rubber disk is replaced with a valve insert, valve flap and rubber insulating shield.

AVIATION CADET BUSTS.—The many rigid requirements for any mask used with a demand system necessitate continuous research and development by the Materiel Center. As an illustration of one aspect of this research program, reference is made to an extensive anthropologic study of the head and particularly the facial measurements of 1,454 aviation cadets. On the basis of this survey, seven busts, illustrated in figure 44, were designed for use in improving the design of oxygen masks. The most important dimension for this purpose is nasion-menton face length, from nasal root to bony tip of chin. Accordingly, the entire range of this dimension in the cadet series (that is, from 101 to 147 mm) was divided into thirds. The averages of all the forty-five other measurements for the individuals in these groups were calculated and constitute types I (grand mean), IV (lower third), and V (upper third).

Types VI and VII represent similar averages for the extremes in face length; type VI is the *shortest 1 percent* of the population; type VII, the *longest 1 percent.*

To show the errors inherent in subjective estimation of facial proportions, two artificial extremes were constructed about the mean face length for the total series. Type II is the *minimum* found of every other measurement in individuals with this *mean* face length; type III is the corresponding *maximum.*

The requirements that must be considered in the selection of any mask for service are many and varied. The following list is based on numerous reports of service tests and literally thousands of tests in the altitude chamber at Wright Field. In these tests more than 1,000 men have participated, most of them flyers. Their opinions, frankly expressed, have been invaluable in enabling conclusions to be reached and in making recommendations as to mask design.

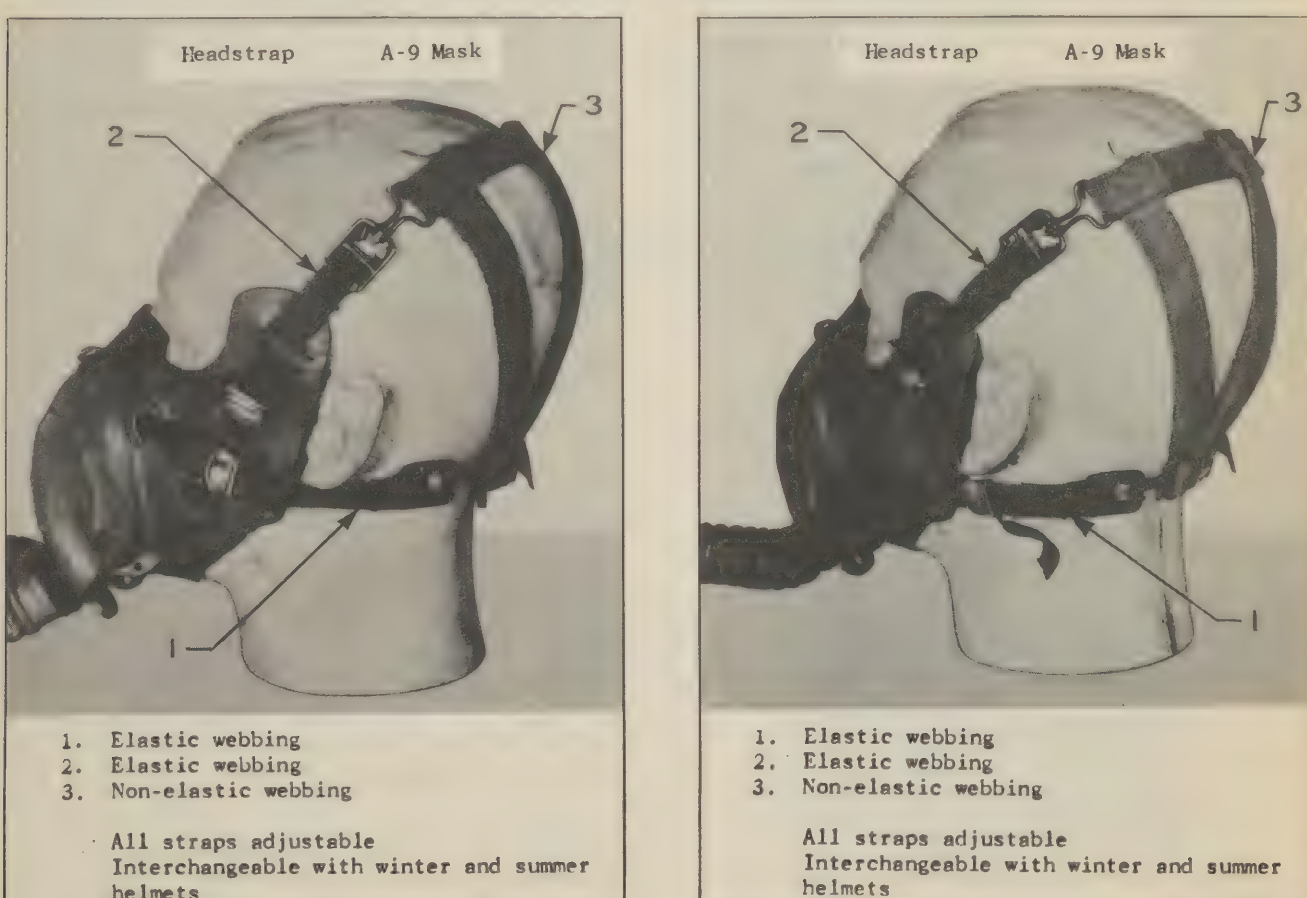
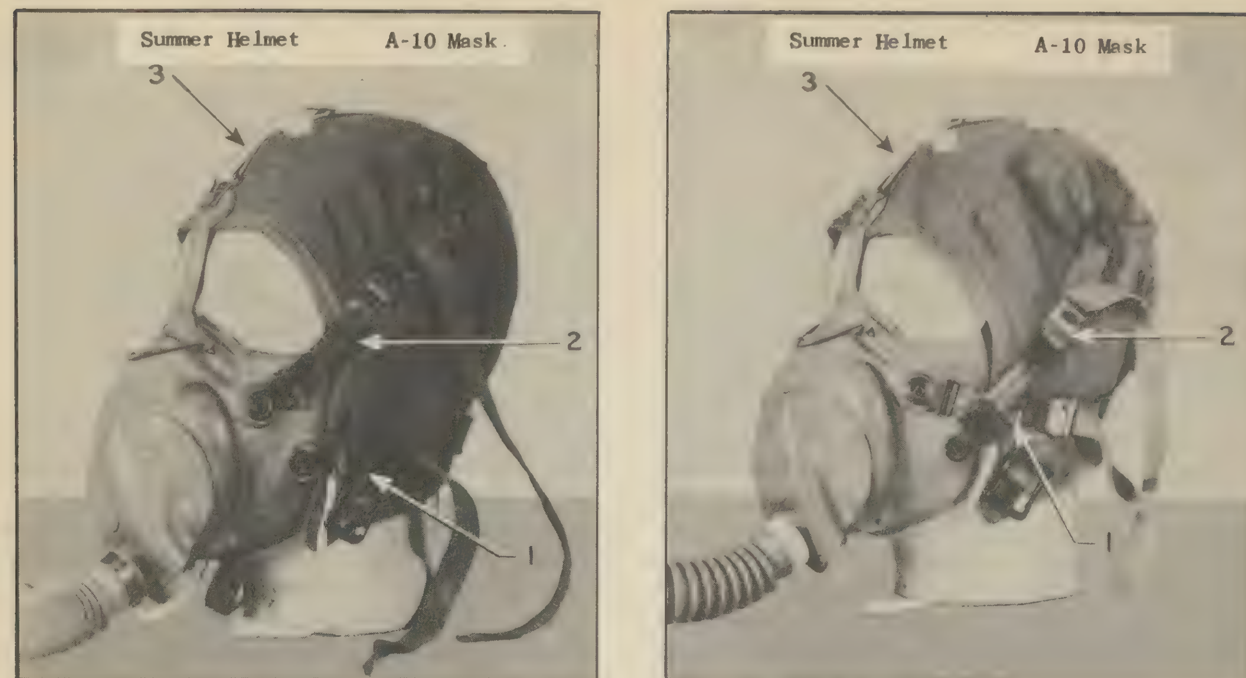


Figure 42—The type A-9 mask (Specification 3125) worn without helmet: a, with helmet straps crossed; b, with helmet straps worn parallel.



1. Non-elastic webbing
2. Non-elastic webbing with spring section
3. Non-elastic webbing

All straps adjustable, spring section upper position
Interchangeable with winter helmets and headstraps

1. Non-elastic webbing
2. Non-elastic webbing with spring section
3. Non-elastic webbing

All straps adjustable, spring section upper position
Interchangeable with winter helmets and headstraps

Figure 43—The type A-10 mask (Specification 3134): a, with helmet straps worn parallel; b, with helmet straps worn crossed.

Figure 44—Seven types of busts, representing the chief types of heads and faces, based on intensive study of 1,454 aviation cadets by the Army Air Forces Materiel Center.

TENTATIVE REQUIREMENTS FOR OXYGEN MASKS DESIGNED FOR USE WITH DEMAND REGULATORS.

1. Leakproof fit. This depends on:

a. Shape of the face.

b. Whiskers; whether long or short.

c. Facial movements, including, particularly, head movements involved in speaking, yawning, or chewing.

d. Body movements, including, particularly, head movements and, therefore, the man's job, whether he is a pilot, gunner, navigator or bombardier.

e. Accelerative force. Will the mask remain in place at 10 *g?*

f. Inspiratory resistance. A mask that leaks in quiet breathing may be tight when a high negative pressure is produced with the inspiratory tube closed.

g. Cold. The rubber should retain its elasticity at –45° C.

h. Leakage must not exceed 5 percent in rest or work in 95 percent of the subjects tested.

2. Comfort. This depends on:

a. Type of suspension.

b. Area and physical characteristics of contact surfaces.

c. Fit over the nose. This is a common source of discomfort, particularly when the head is turned back where the wearer wishes to look directly upward.

d. Duration of use. Many masks are comfortable for an hour, but become uncomfortable after a longer time.

e. Adaptation to Air Corps goggles is required.

f. Cold. Unprotected areas of the face may freeze. Rivets may conduct away enough heat to make the points of contact with the face uncomfortably cold or actually freeze spots on the face.

g. Drainage of condensed water.

3. Simplicity.

a. Adjusting straps should not be complicated; a suspension that can be fastened with one hand is desirable if leakproof fits can be secured. This is important for quick removal and readjustment in an emergency—as in vomiting.

b. Minimum of mask sizes and of suspension types is highly desirable.

4. Ruggedness.

a. Mask should have enough body to make an instantaneous tight fit when it is put on after first adjustment.

b. Any plastic parts should withstand rough handling, in temperatures of as low as –45°C.

c. Valves should be secured so as to prevent leakage through or around them, even despite rough handling. At the same time, they should be accessible for repair in case of failure or defect.

d. The connecting corrugated tube should be reasonably kinkproof, and be freely flexible at –45°C.

e. All hose connections must be wired, clamped or taped securely.

f. Microphone must be well secured.

5. Insulation. Continuous operation on a subject for at least one hour in the cold chamber at –40°F or C and an altitude of 30,000 feet in a wind of 5 to 15 miles per hour is required, any procedure that frees ice while the mask is in use being permissible.

6. Field of vision. This should be unrestricted either by protuberances or by interference with head movements. There should be no interference with standard gun and bomb sights.

7. Injury from metal parts in an accident should be minimal.

8. Maximal protection should be offered against flash burns.

9. Ease of cleaning and sterilization is required.

10. Quantity of rubber required must be minimal.

11. Effects of high *g* (mentioned in paragraph 1). Displacement of a mask during high *g* depends on the weight of the mask and on the tautness, length, and elasticity of the suspension.

FITTING THE MASK TO THE FACE.—The A-9 and A-10 masks have been designed, it has been aptly said, to fit the face like a glove. Consequently, it is then a problem of first importance to fit each face with a mask. Since there are four sizes of the A-10 and each size may be suspended by crossed or parallel straps, eight possible combinations are available from which to select the best fit. General instructions concerning fitting the A-9 or A-10 are:

1. It is not necessary for any single strap of the A-10 mask to be pulled up tightly to secure a leakproof fit. If the wearer will remember this, it will materially add to his comfort.

2. For small or long and narrow faces, the best fit will probably be obtained using the straps in the position in which they are when the mask is received (crossed as in figure 43*b*).

3. For broad or full faces, the straps will probably best be used uncrossed (figure 43*a*).

4. To change the straps suspension from *crossed* to *uncrossed,* remove the straps from the guide slots and turn the swivel rivets.

5. Once a proper fit is obtained, the adjustments need not be disturbed unless to eliminate normal stretch from service use.

6. Excessive beard stubble will cause the mask to leak and function imperfectly.

7. If the edge of the mask causes discomfort or visual interference, the mask can be trimmed back with the scissors as far as the horizontal rib.

8. Carelessness in fitting the oxygen mask may cost not only the wearer's life but others' lives as well.

BE CAREFUL—BE SURE—BE SAFE.

Mask Leaks a Serious Hindrance to a Flyer's Performance at Altitude.—With a mask which fits perfectly, pure oxygen is supplied at altitudes of more than 30,000 feet. At altitudes of more than 37,500 feet, even though a perfect mask and regulator do supply pure oxygen, the concentration is not fully adequate. Even a 30 percent leak at 30,000 feet has no serious effect unless heavy work is attempted, but as the altitude increases above 30,000 feet, a leaking mask becomes more and more hazardous. The seriousness is enhanced by the fact that large leaks in masks may increase with altitude because of the decreasing density of the air. The importance to flight personnel of having a mask that is leakproof cannot be over-emphasized.

The Problem of Mask Fitting the Duty of the Group or Squadron Oxygen Officer.—A routine procedure for determining mask leakage is to hold the thumb over the end of the inspiratory tube and inhale gently. If the mask does not leak, it will offer resistance to the inhalation and tend to collapse on the face. Sharp or strong inhalations are deceiving, since they tend to seal the mask on the face. Even gentle inhalation may fail to reveal serious leaks.

The Oxygen Officers' Test Set.—A better method for testing mask leakage has been worked out and field equipment has been specially designed at the Materiel Center, Wright Field. This is being sent to group and squadron oxygen officers (figure 45). The gas analyzer used in this equipment, illustrated in figure 46, was developed by P. F. Scholander and bears his name. The method makes it possible to test for nitrogen in the air within the mask after the wearer has been breathing through the system for six minutes. Since the intake from the regulator is 100 percent oxygen, any nitrogen which appears in the mask must be derived from air that is leaking into the system around the mask. In the Scholander analysis, a measured volume of a mixture containing nitrogen, oxygen, carbon dioxide, and water vapor is taken directly from the mask, preferably from the microphone turret as shown in figure 47 by means of a hypodermic syringe. This sample is then injected through the heavy tubing into the buret (figure 48). All gases but nitrogen are absorbed. The buret is calibrated to read in percentages of nitrogen. A percentage of 4 or less is satisfactory. Between 5 and 8 is objectionably high, and anything more than 8 indicates an unacceptable fit. Full directions will go with the equipment.

Every attempt is being made to perfect a mask and suspension which are universal in fit, but even though this is accomplished, the proper fitting of the mask and proper care of this item of oxygen equipment are absolutely essential.

Figure 45—A unit set to be used by the oxygen officer. Here it is ready for shipment.

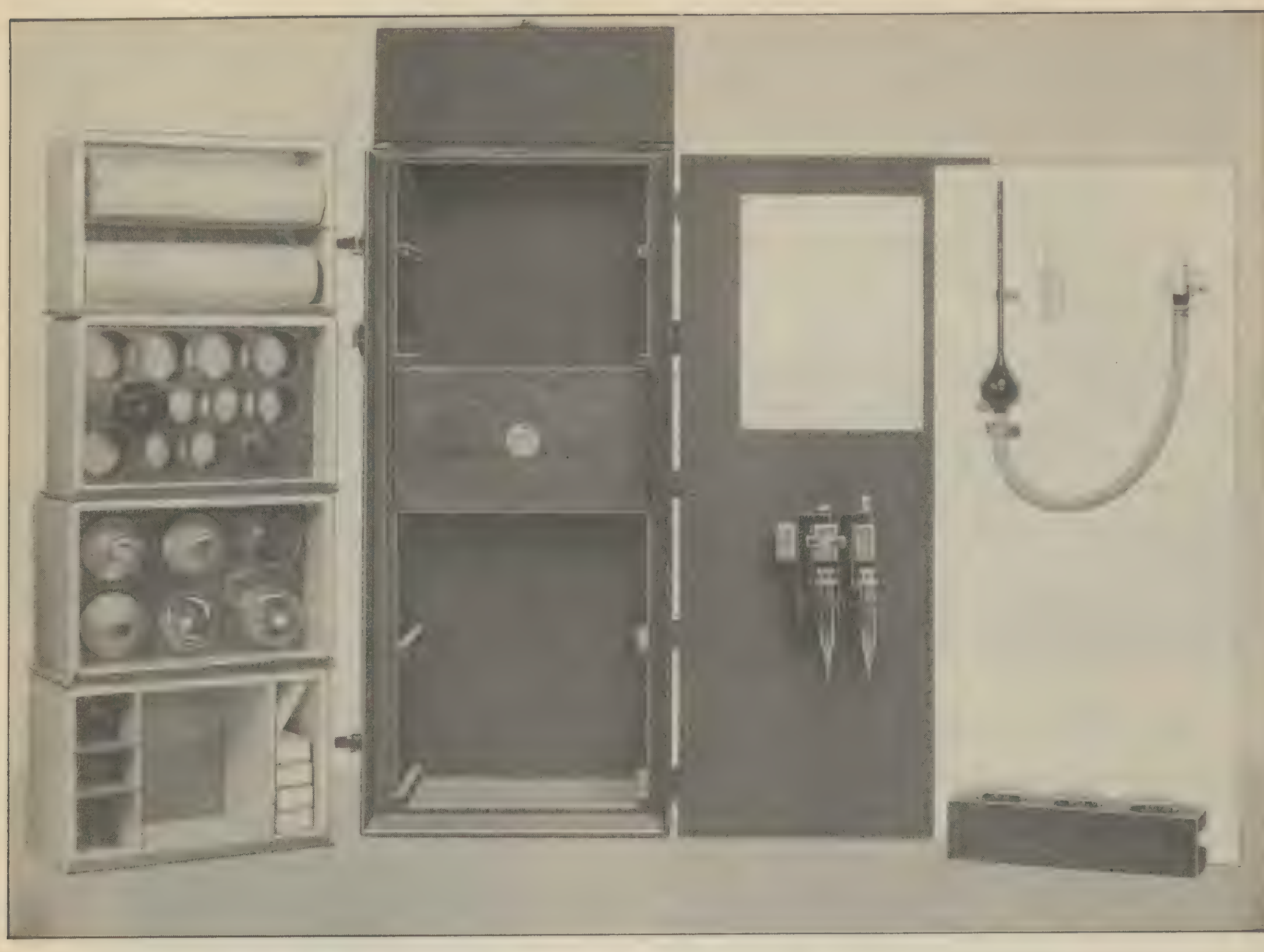


Figure 46—Field unit for testing masks. The Scholander analyzer is mounted on the board to the right. Reagents and spare parts are contained in the drawers shown at the left.

Precautions in the use of the demand system are as follows:

Before the Flight:

1. Check pressure of oxygen tank (it must not be less than 400 p.s.i.).

2. Check emergency flow, to show that lines are clear, and close valve tightly.

3. Make sure that knurled collar at outlet end of regulator is tight.

4. Be sure male end of rapid disconnect has its rubber gasket in place.

5. Be sure male end of rapid disconnect fits snugly the orifice of the hose from the regulator at your station. A pull of 10 pounds or more should be required to separate the two.

6. Have mask adjusted for particular helmet or headstrap to be used.

7. Clip the oxygen supply hose by means of spring clip onto the clothing or parachute harness close enough to the face so that the tube of the mask will permit free movement of the head without kinking or pulling.

8. Be sure the auto-mix is in the "ON" position.

In the Air:

1. Manipulate mask to free it of ice at regular intervals when temperature is low enough to cause ice formation in the mask.

2. When mask is first put on or when it is replaced after temporary removal, always check for leak by blockage and gentle inhalation.

3. Should signs of impending anoxia appear, open the emergency, but only in absolute necessity.

4. Check oxygen pressure gages frequently.

On Return to the Field:

1. Wipe mask dry, or better, wash with soap and water.

2. Lend your mask only in extreme emergency.

3. Inspect for cracks and leaks in facepiece of mask.

4. Change strap adjustment only to take up on natural stretch slack.

SUMMARY.—In summary, the demand system supplies an adequate oxygen supply at altitude automatically. The mask must fit without leakage on the face, thus insuring the inspiration of whatever mixture of air and oxygen is coming from the regulator. The regulator can be used for delivery of pure oxygen in emergencies or on flights when denitrogenation is desired. Use of the auto-mix in the "OFF" position or of the emergency valve is an undesirable and unnecessary waste of the aircraft oxygen supply. On every flight, unless otherwise ordered, the auto-mix should be on. This is the correct method for securing greatest economy and also an adequate supply of oxygen.

Figure 48—The sample of gas obtained from the microphone turret of the mask, as seen in figure 47, is now injected into the Scholander analyzer.

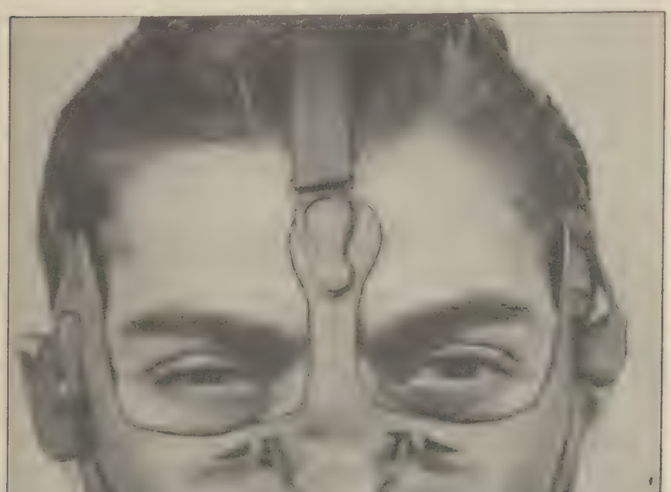
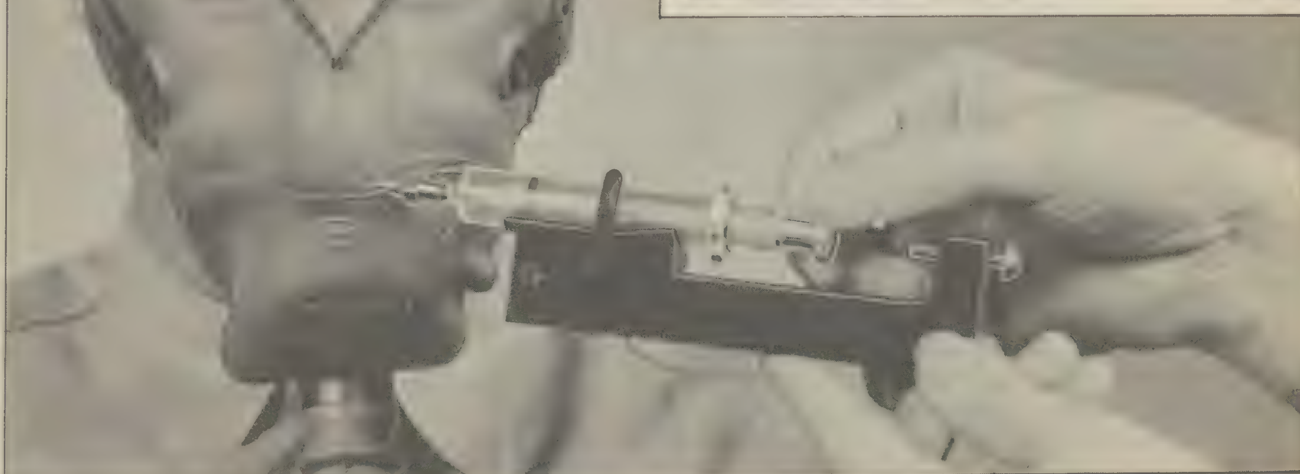



Figure 47—Withdrawal of a sample of gas from the microphone turret of a type A-10 mask, by means of a 5 cc syringe used with the Scholander apparatus.

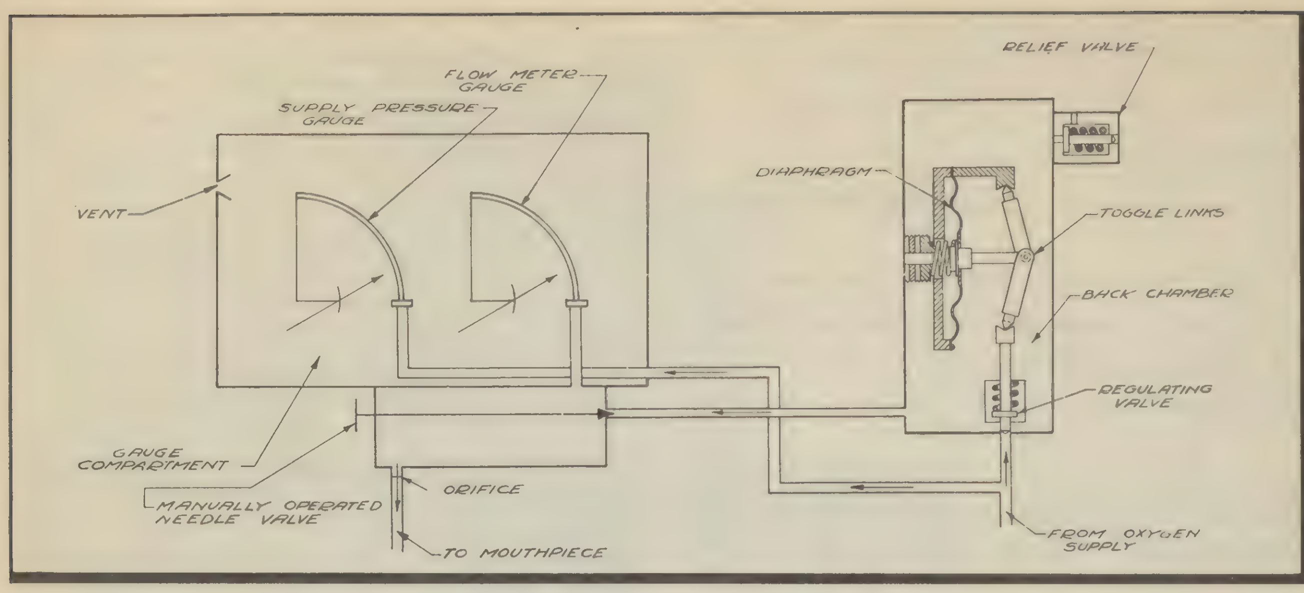


Figure 49—Schematic diagram of the type A-6 oxygen regulator.

Oxygen Regulators

THE TYPE A-6 OXYGEN REGULATOR.—This was used for dispensing oxygen in conjunction with the pipestem. A schematic drawing of the regulator is shown in figure 49. The instrument is divided into a back chamber and a front gage compartment. Oxygen enters the back chamber from the supply tank under the control of a regulating valve. This valve is operated by a spring-restrained diaphragm through a toggle-link mechanism and automatically maintains a constant reduced pressure in this chamber of about 30 pounds per square inch throughout the wide operating pressure range of a standard high-pressure supply cylinder. A relief valve is provided in the back cover to protect the mechanism from overpressure in the event of failure in the regulating valve. From the back chamber the oxygen flows through a needle valve which is manually operated by a knob from the front of the instrument. From this point, a calibrated orifice meters the flow to the pipestem. The flow indicator, which is a Bourdon tube pressure gage, indicates directly the pressure difference across the calibrated orifice and is calibrated to indicate the flow corresponding to this pressure difference. The dial is marked directly in altitudes for simplicity, and the proper flow for use at any altitude under normal conditions is obtained when the pointer is set at the corresponding graduation by opening or closing the needle valve. The cylinder pressure indicator, also a Bourdon tube type, is connected directly to the line from the oxygen tank and shows the condition of the oxygen supply. The outlet fitting of the regulator contains a calibrated orifice and must never be replaced with a standard hose nipple, which does not contain this orifice. This regulator is intended primarily for use with the pipestem, and as such, dispenses the large quantities of oxygen which are necessary in using the pipestem. When used with the pipestem, the regulator should be set at the altitude at which the airplane is flying.

USE OF THE A-6 REGULATOR AND A-8 MASK.—There may sometimes be occasion for using an oxygen mask of the A-8 series with a type A-6 regulator. Of course, the oxygen mask, being much more efficient, does not require the large quantity of oxygen that the pipestem does. Therefore, when the type A-6 oxygen regulator is used with an oxygen mask, it will suffice to set the regulator at the 20,000 feet altitude mark and leave it at that setting for all altitudes. At this setting, it will supply more than is necessary with the A-8 series mask, at all altitudes.

REGULATORS OF THE A-8 SERIES *(Figure 51)*.—These are very similar to type A-6. They are intended to be used with masks of the A-8 series only; and, as such, the quantity of oxygen dispensed by them has been greatly reduced. This has been accomplished by decreasing the size of the calibrated orifice and by recalibrating the Bourdon pressure gage. The type A-8 regulator can be quickly distinguished from the A-6 regulator because the knob is distinctly marked "USE WITH MASK ONLY" (figure 50).

Since this regulator has been calibrated for use with the mask, it should never be used with a mouthpiece or pipestem, and whenever it is used with a mask, it should be set as marked.

The outlet of the regulator is equipped with an oxygen regulator coupling fitting which permits the mask apparatus to be readily attached, bayonet fashion, to the oxygen regulator.

REWORKED A-8 REGULATORS.—The type A-8 regulator provides enough oxygen at 30,000 feet for people at rest or for those doing light work, such as the pilot does. But the flow is insufficient for heavy work, such as is required of a gunner engaged in swinging a gun in combat. To supply more oxygen at 30,000 feet, the calibrated orifice in the outlet fitting of the regulator has been drilled out larger. Regulators reworked in this fashion are known as "REWORKED A-8 REGULATORS" and can be identified by an X marked on two opposite sides of the hex on the outlet nipple.

A-9A REGULATOR.—The increased flow furnished by the reworked A-8 regulator is necessary at 30,000 feet and is not necessary at 10,000 feet. The A-9A regulator has both the outlet orifice and the flow indicator dial changed and recalibrated to give an increased flow at 30,000 feet but not to increase the flow at 10,000 feet.

HIGH VERSUS LOW PRESSURE.—Both the type A-6 and the type A-8 regulators are intended for use with high-pressure oxygen supplies. In the discussion of cylinders below, the change from high pressure to low pressure will be described. The present use of low-pressure oxygen cylinders has necessitated regulators designed to operate on low pressure. These are the type A-9, the reworked A-9, and the A-9A oxygen regulators. In all other respects they are identical with the type A-8, the reworked A-8, and the A-8A, respectively. The only difference is that the A-9 series regulators are designed to operate on a maximal pressure of 500 pounds per square inch and a minimal pressure of 30 pounds per square inch.

DEFICIENCIES OF THE CONSTANT-FLOW REGULATORS.—At low temperatures, some difficulty has been experienced with freezing at the expansion valve of the A-6 regulator. With the type A-8 regulator the flow is smaller and the tendency to freeze is not so great. With the type A-9 regulator the tendency to freeze is still less. The decrease in pressure with the type A-9 regulator is only from a maximum of 500 pounds to approximately atmospheric pressure; whereas, in the other types, the decrease in pressure is from a maximum of 1,800 pounds per square inch. This small decrease in pressure at the expansion valve causes a much smaller decrease in temperature and the danger of freezing-out moisture in the oxygen is greatly decreased.

The regulators are manual types and, as such, require attention on the part of the flyer. It would be highly desirable if the dispensing of oxygen were completely automatic and required no attention whatsoever from the airplane crew members.

At any one altitude the regulator dispenses a continual and constant flow of oxygen. There is no pro-

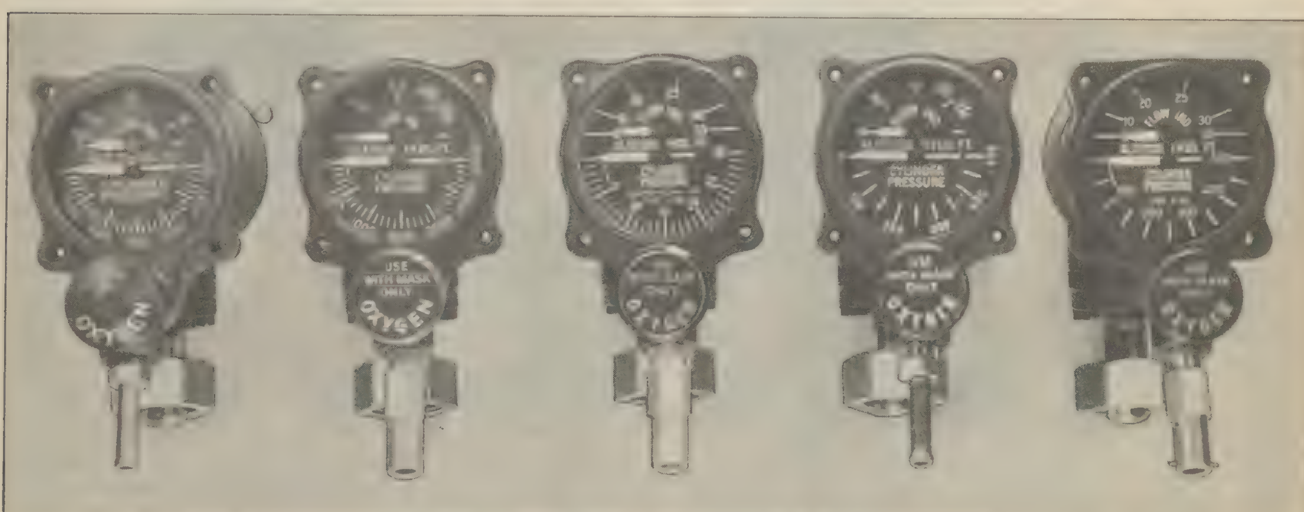


Figure 50—Oxygen regulators of the type A-8 series.

vision made for supplying the flyer momentarily with the larger quantities of oxygen which may be necessitated by a crew member's indulging in some form of strenuous exercise. This could be a serious deficiency in combat.

TYPE A-11 REGULATOR.—The type A-11 regulator automatically varies the flow of oxygen as the altitude increases, and is capable of taking care of as many as fifteen men at one time. The regulator is still of the continuous-flow type. It is used in high-altitude troop transport airplanes for supplying oxygen to the troops.

GROUND FLOW CHECK METER.—The rate of flow of all the manually controlled continuous-flow regulators should be periodically checked to make sure that they are not too low. The ground flow check meter, Specification No. 40400, should be used for this purpose. This instrument permits the checking of the regulator flows while the airplane is on the ground. Complete operating instructions are on the instrument.

The Demand System

INTRODUCTION.—From the foregoing discussion of the inadequacies of the free-flow system, it is clear that the stimulus to further development of oxygen systems arose from a desire to eliminate the waste of oxygen during the user's *expiratory* and *pause* phases of respiration, to provide oxygen in accordance with the varying physiologic needs of the user rather than by any predetermined schedule, and finally, to make the whole system automatic so that no attention is required from the user once he dons his mask, regardless of temperature, wind, and accelerative forces. In combat operations, the hazard of low temperatures alone is grounds for modification or abandonment of the present continuous-flow oxygen system. The following dispatch dated August 31, 1942, Cairo, Egypt, and published in the *Dayton Herald* of August 31, 1942, is a convincing record:

"Sgt. Norman E. Stiffler, a gunner from Commodore, Pa., who took part in the Tobruk raid, still was thanking Second Lieut. Joseph T. Houston of Floresville, Tex., today for saving his life when his oxygen supply was cut off and he collapsed unconscious.

"Houston, the navigator, revived Stiffler by forcing oxygen into the gunner from his own mouth.

"The bomber was coming in at high altitude and was nearly over the target when the incident occurred. Stiffler and his fellow gunner, Sgt. Charles Holt of Selma, Calif., were watching for enemy fighters and in their excitement failed to notice that their oxygen masks had been frozen.

"Stiffler collapsed and his mask was torn from his face. Holt tried to help him but was too weak. Other crewmen pulled Holt to a warmer section of the plane, but they were unable to move the unconscious Stiffler along the narrow catwalk. Finally an emergency bottle of oxygen was found and the tube shoved into Stiffler's mouth.

"Sgt. James Anderson of Joiner, Ark., applied artificial respiration while another crewman tried to force the oxygen into Stiffler, but the effort was failing when Houston began breathing directly into the victim's lung, timing himself with Stiffler's faint breathing.

"He soon recovered consciousness, the crew carried out its mission over Tobruk, and then the pilot dropped to a lower altitude where all could breathe normally. Stiffler was taking care of his normal duties when the plane returned to its base."

The answer to the problems thus posed is found in the demand regulator system. The basic principle is a diaphragm-operated flow valve which is opened by the suction of the user's inspiration and closes automatically when that suction ceases. At present, the Army Air Forces are procuring two types of demand regulators, the A-12 and the A-13. The demand regulator, type A-12, is one which supplies the flyer the proper mixture of air and oxygen at all altitudes every time he inhales, and then shuts off when he exhales. The percentage of oxygen being delivered to the user increases with increasing altitude, becoming 100 percent at an altitude of about 30,000 feet. This action, being completelv automatic, makes unnecessary any attention on the part of the flyer. The device is installed as a permanent fixture of the plane, there being a demand regulator for each station in the plane.

PRINCIPLE.—In figure 51 it is shown how the demand regulator works. Every time the user inhales, he applies a small degree of suction to the regulator. This suction is sufficient to deflect a diaphragm, which is connected to a valve, thus causing the valve to open. Oxygen comes out. It requires only a few tenths of an inch of water suction to operate the regulator. As soon as inhalation ceases, the suction is no longer applied, a spring returns the diaphragm to its original position, and the valve is shut off. The operation is entirely automatic. The inhalation and exhalation of the user are all that operate the regulator.

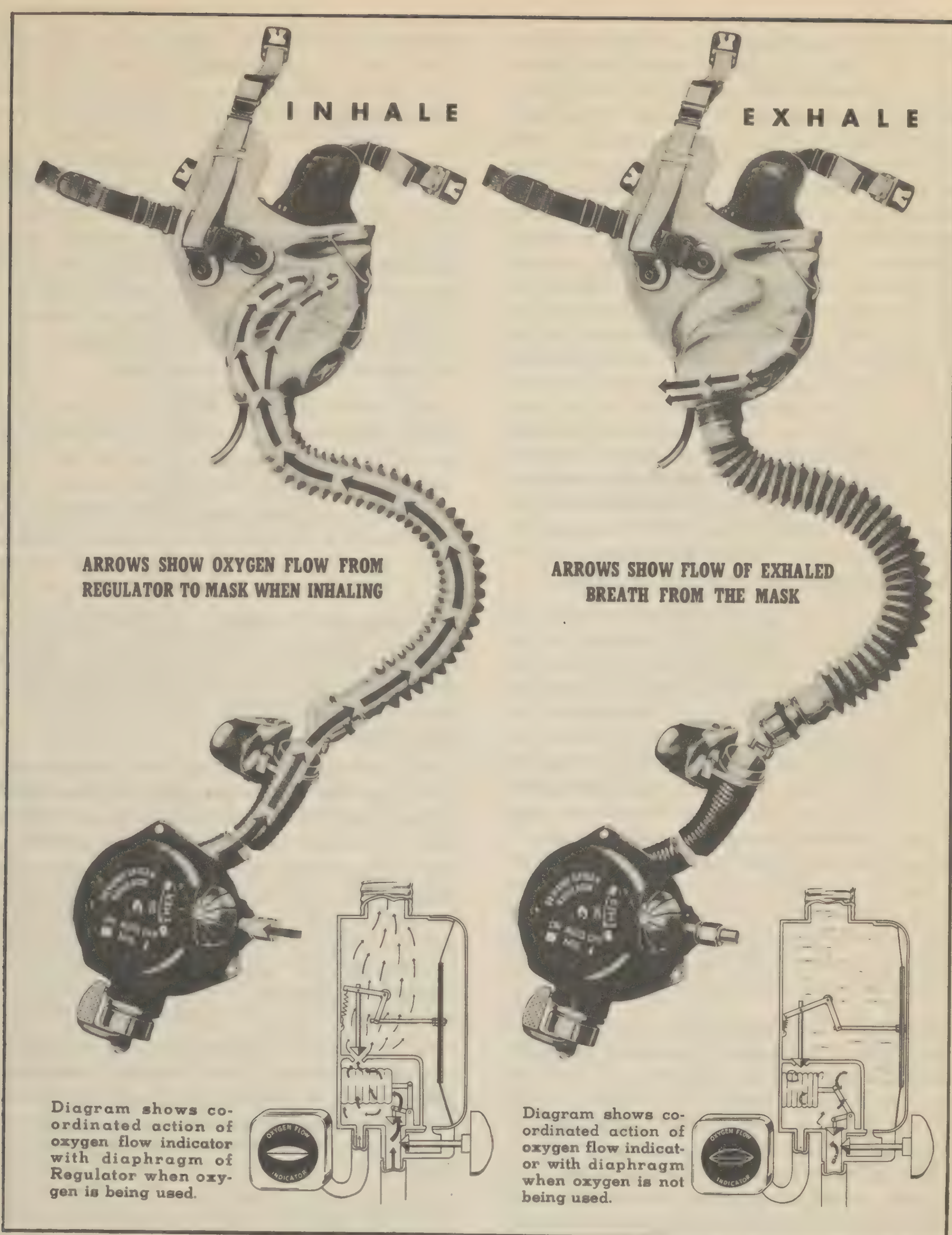


Figure 51—Diagrammatic illustration of the method of operation of the type A-12 oxygen regulator used in conjunction with the type A-9 or A-10 mask.

ECONOMY.—In addition to furnishing oxygen on demand, the type A-12 regulator has another feature: It mixes air with the oxygen and varies the mixture according to the needs of the altitude. It is obvious that at sea level a person does not need any added oxygen. Air which contains 21 percent oxygen is adequate. Therefore, the demand regulator does not have to add any oxygen to the mixture at sea level. As the altitude increases, a person has to breathe a mixture which becomes richer and richer in oxygen in order to maintain normal sea level conditions. Finally, at 33,000 feet, 100 percent oxygen is required to simulate normal conditions. In figure 52 is shown how the regulator accomplishes this. An evacuated metallic bellows, an aneroid control similar to that found in altimeters, controls an air port and an oxygen port. At sea level, the air port is wide open and the oxygen port is closed. As the altitude increases, the metallic bellows expands, gradually closes the air port, and at the same time gradually opens the oxygen port. Finally, at an altitude of about 30,000 feet, the air port is closed and the oxygen port is wide open. Thus, as the altitude increases, the mixture becomes richer and richer in oxygen.

It is very essential that the regulator mix air with the oxygen at lower altitudes. It is unnecessary to furnish pure oxygen at low altitudes, and in fact, to do so would be uneconomical. A person actually would use more oxygen at 15,000 feet than at 30,000 feet if he breathed pure oxygen at both altitudes! Here is the reason: The average lung ventilation rate of a resting person is about 9 liters per minute. At an altitude of 30,000 feet, because of the low pressure and low density of the atmosphere, nine liters is the equivalent of 2.7 liters at sea level. Nine liters at 15,000 feet is the equivalent of 5.1 liters at sea level. Thus, if we use sea level as the standard for measurement, we see that a person breathing pure oxygen would breathe 2.7 liters per minute at 30,000 feet, 5.1 liters per minute at 15,000 feet, and 9 liters per minute at sea level.

AUTOMATIC REGULATION.—In normal use, the operation of the A-12 regulator is completely automatic. Two manual controls are provided for use in special instances. One of these is labeled "AUTO-MIX" and the other "EMERGENCY." AUTO MIX stands for automatic mixing. There are only two positions for the auto-mix—ON and OFF. The normal position is ON. When the auto-mix is ON, the regulator automatically mixes the proper amount of air with the oxygen at all altitudes. When the auto-mix is OFF, the air port is shut off and no air can be taken into the regulator. The regulator will give pure oxygen at all altitudes. Notice that when the auto-mix is ON, the radiant spot on the auto-mix handle lines up approximately with the radiant spot on the regulator. When the auto-mix is OFF, the radiant spot on the handle is hidden.

USE OF THE AUTO-MIX.—At an altitude of 30,000 feet, the regulator is required to furnish more than 96 percent of added oxygen. Therefore, at this altitude, it makes little difference whether the auto-mix is on or off. However, if a flyer turns the auto-mix off, he might descend to a lower altitude later and fly there for an extended period and forget to turn the auto-mix on again. He will waste his oxygen and might use up his supply before the mission is completed.

On extended flights at altitudes of 30,000 feet and higher, if the medical advice is to denitrogenate on the ground and use pure oxygen all the way up, to avoid the effects of aeroembolism, then the auto-mix must be turned off so that pure oxygen will be furnished. When the auto-mix is off, the regulator is still a demand regulator and will automatically furnish oxygen on demand, but it will be *pure oxygen* and will contain no air.

ECONOMY OF REGULATORS COMPARED.—Careful comparison of the rate of oxygen usage with demand regulators and with A-9A constant-flow regulators shows that the use of a demand system is more economical.

The calculations given for demand regulators in table 7 are based on the assumption that the ventilation of the lungs is 9 liters per minute, measured at 20° C (68° F) and ambient pressure. If this assumption is made, it is only necessary to determine the proportion of air admixed by the regulators. This has been done for two makes of A-12 regulators in the altitude chamber and the average performance used for making the calculations shown in table 7. The performance of the A-9A constant-flow regulator has also been tested in the altitude chamber at each of the indicated altitudes.

As noted in table 7, and as said before in this section, the demand system is more economical than the constant-flow system, although the difference is not striking except at extreme altitudes. The A-12 regulator of the Pioneer make is needlessly wasteful of oxygen at altitudes up to 10,000 feet (where oxygen should be used in night operations), but it is very economical at 20,000 feet. Both regulators meet A-12 specifications, but inherent characteristics in design account for the considerable differences in oxygen admixed below 30,000 feet.

TABLE 7

Average Volume* of Tank Oxygen Supplied at Altitude by Three Regulator Types

(Subject at rest, assuming a respiratory volume of 9 liters per minute at ground level.)

Altitude, Feet	*Demand* 80 Pioneer Reg-ulators (A-12) Auto-Mix On	21 Aro Reg-ulators (A-13) Auto-Mix On	*Constant-Flow* 21 A-9A Reg-ulator, Setting Adjusted to Altitude
	Liters per min., NTP	*Liters per min. NTP*	*Liters per min. NTP*
Ground	1.62	0.7	0.0
10,000	1.36	1.06	1.43
20,000	1.37	2.23	1.89
30,000	2.58	2.64	2.74
35,000	1.66	1.66	2.91
40,000	1.18	1.18	3.28

* Volumes are calculated to normal temperature and pressure.

OXYGEN "RANGE."—Oxygen "range' depends on the number of men, the level of activity, the altitude and, by no means least, the characteristics of the oxygen regulator. This is of so much importance that estimates have been tabulated in table 8 of the expected life of an F-1 cylinder as used in straight forward flying with the two makes of A-12 regulators.* Calculations are also included that show the extreme wastefulness of using the auto-mix control "off" at low altitudes and of using the emergency supply needlessly.

THE AUTO-MIX.—As indicated in table 8, the range of the oxygen system may be seriously shortened if the auto-mix control is turned to the "off" position needlessly. In this position the regulator supplies 100 per cent oxygen to the user on demand. The auto-mix "off" adjustment is for use when the flyer wishes to protect himself against aeroembolism, either by exercising and breathing oxygen before his high-altitude flight or merely by breathing oxygen from the ground up. This need arises only in flights at altitudes of more than 30,000 feet. Under other circumstances the auto-mix "off" should not be used. *It is wasteful at intermediate altitudes.*

THE EMERGENCY VALVE.—Examination of figure 52 will reveal an emergency valve. Opening this valve converts the demand system to free flow. It is an emergency device for use only if the demand system fails to function. As indicated in table 8, it is extremely wasteful if used when not needed. The successful completion of a long, high-altitude mission will depend on the economical use of the available oxygen supply. Opening the emergency valve, unless absolutely essential, as for the revival of a member of the crew, is comparable to the operation of engines on needlessly rich mixtures. The oxygen supply for high-altitude missions can limit the range as certainly as the supply of gasoline limits it. This supply must be conserved!

*In a subsequent section the oxygen duration for each type of cylinder and regulator will be given.

TABLE 8

Oxygen "Range" With the F-1 Cylinder Using A-12 Demand Regulators Manufactured by the Aro Equipment Corporation* and by the Bendix Aviation Corporation, Pioneer Instrument Division*

(It is assumed that the flyer's inspiratory volume is 9 liters per minute, NTP, at ground level. It is further assumed that the initial pressure is 400 pounds, and the final pressure, 50 pounds. With this pressure drop, the F-1 cylinder delivers 390 liters of oxygen, NTP.

The very short life of the oxygen supply when the emergency is turned full on is strikingly illustrated by the last column. *Don't turn on the emergency except in actual emergencies.)*

Altitude Feet	*Automix "On"* Aro hrs	Pioneer, hrs	*Automix "Off"* Aro or Pioneer, hrs	*Emergency "Full On"* Aro, hrs	Pioneer, hrs
5,000	31.8	3.1	0.7	0.06	0.05
10,000	4.4	3.3	0.7	0.07	0.05
15,000	2.2	3.5	0.8	0.07	0.05
20,000	1.4	2.3	0.8	0.07	0.05
25,000	1.1	1.2	0.8	0.07	0.07
30,000	0.8	0.8	0.8	0.08	0.07
35,000	0.9	0.9	0.9	0.08	0.07
40,000	1.0	1.0	1.0	0.08	0.07

*The two makes of regulators comply with specifications. The specified performance covers a wide range: The reason the oxygen "range" differs so much is that the actual performance of the regulators is markedly different. The Aro is the more economical at low altitudes while the Pioneer is superior in economy at 15,000 to 20,000 feet.

OPERATION of the AUTOMATIC AIR-MIX

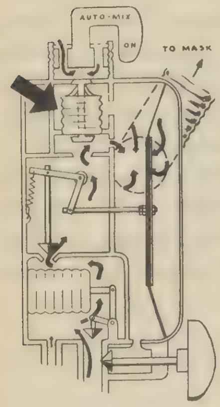


DIAGRAM OF OXYGEN MIXTURE AT 30,000 FEET

At 30,000 feet and above the Auto-Mix sylphon because of barometric pressure shuts off all outside air, permitting only pure oxygen to flow through the Regulator. GrAY arrows indicate the movement of oxygen from the supply line to the mask.

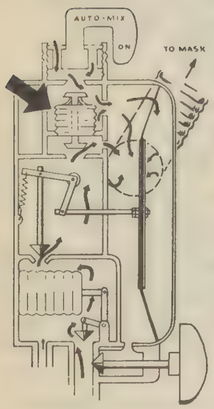


DIAGRAM OF OXYGEN MIXTURE AT 10,000 FEET

At intermediate altitudes the Auto-Mix sylphon controls a variable mixture of oxygen and air. The percentage of oxygen depending on the altitude. All of this is automatically controlled by the action of sylphon. The higher the altitude the greater is the percentage of oxygen flow. The black arrows indicate incoming air and the grAY arrows indicate the incoming oxygen.

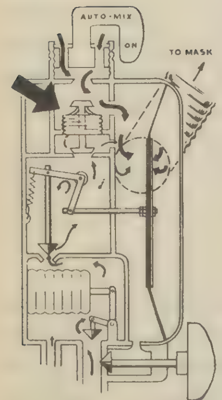


DIAGRAM OF OXYGEN MIXTURE AT SEA LEVEL

At sea level the Auto-Mix sylphon is completely depressed because of the barometric pressure; thus stopping most of the oxygen flow through the Regulator. Black arrows in illustration show the incoming air as it flows through the Auto-Mix into the Regulator and to the mask. Small grAY arrows indicate trickle of oxygen flow into mixing chamber.

FOR USE IN CASE OF EMERGENCY

Prior to flight always check this knurled collar. **It must be TIGHT.**

If Regulator fails to function, turn on Emergency Valve. This allows a constant flow of oxygen to the mask direct from the supply line. Flow indicator will not operate under this condition, and oxygen will flow from the supply line at a higher rate. Watch your pressure gauge.

EMERGENCY "ON"

When Emergency Valve is opened the grAY arrows indicate the flow of oxygen from supply line direct through the Emergency Valve and Regulator to the mask.

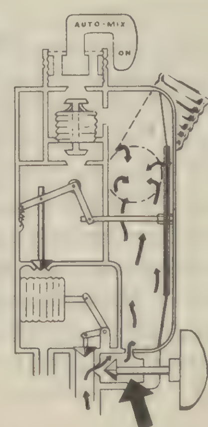


Figure 52—The mechanism of the type A-12 oxygen regulator.

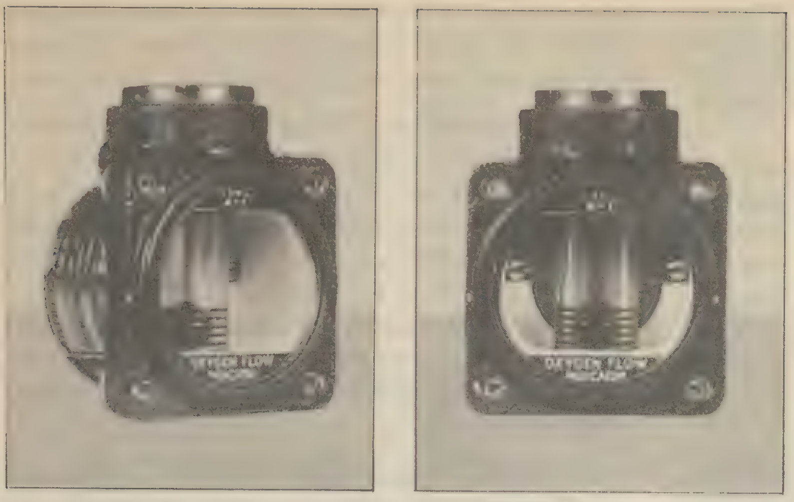


Figure 53—Two views of the type A-1 flow indicator (ball in glass tube).

Figure 54—The type A-3 flow indicator (blinker).

FLOW INDICATORS.—Either of two types of flow indicators is used in conjunction with the A-12 demand regulator. The type A-1 flow indicator, shown in figure 53, consists of a ball in a glass tube which is inserted directly in the supply line to the regulator. Every time oxygen flows from the regulator, the ball bounces up in the glass tube. When the flow stops, the ball slowly falls. The type A-3 flow indicator, shown in figure 54, consists of an "eye" that "blinks" open and shut with the intermittent flow of oxygen from the regulator. The "blinking eye" does not operate when oxygen flows from the regulator emergency valve. These two flow indicators indicate only that oxygen is flowing from the regulator. They do not indicate, necessarily, that enough oxygen is flowing. The flyer should not be surprised if the flow indicator shows that no oxygen is flowing from the A-12 regulator when the airplane is on the ground and when the auto-mix is "on." *Remember that the regulator is not supposed to add any oxygen at ground level, although as a matter of fact, some A-12 regulators do supply oxygen even at ground level.*

PRESSURE GAGE AND SIGNAL LAMP.—These are mounted on the same panel with the flow indicator. The pressure gage shows the pressure of oxygen in the supply cylinders for that station. The signal lamp is actuated by a pressure signal in the supply line, and an amber light appears when the supply pressure falls below 100 p.s.i. When the light flashes, only one-seventh of the original supply remains and the pilot should descend. The supply should not be used when it decreases to less than 50 p.s.i., because no particular performance is required of the demand regulators below that pressure.

DEMAND MASK.—When a demand regulator is used, a demand type of mask must be used. This is the A-9 or A-10 mask and it is decidedly different from the A-8 series masks. A demand type of mask must fit the face well and be as nearly leakproof as possible. All the gas a flyer breathes must come from the regulator, because the regulator accomplishes the proper mixing of air and oxygen. If the mask does not fit well and leaks, air will be sucked in around the edges and will dilute the mixture from the regulator. The oxygen percentage might thus become dangerously low, and might handicap the user and even cause him to "pass out." The demand type of mask is discussed in greater detail elsewhere in this manual.

PORTABLE CYLINDER AND REGULATOR ASSEMBLY.—In large airplanes it is frequently necessary for men to move about during a flight. It is dangerous to move about without oxygen at an altitude at which oxygen is necessary. Portable oxygen equipment is provided to permit such movement to be carried on in safety. In an airplane in which A-12 demand regulators are installed and in which the crew is fitted with demand type masks, the portable equipment must also be of the demand type, because the demand type of mask should be used only with demand equipment.

The portable cylinder and regulator assembly or "walk-around bottle" shown in figure 55 consists of a small type A-4 low-pressure oxygen cylinder attached directly to a type A-13 *pure demand regulator. A pure demand regulator* is a demand regulator that supplies pure oxygen

and mixes no air with the oxygen. Portable equipment is used for such a relatively short time during any flight that the slight economy in oxygen that would be gained by its use is not worth the complication of a demand regulator that mixes air with the oxygen.

The small type A-4 oxygen cylinder contains only about a four to eight minute oxygen supply. However, the regulator contains a filler adapter, through which the cylinder can be recharged directly from the airplane's oxygen supply, by means of portable refilling hoses. In installations of demand systems, every station in the airplane has a portable cylinder and regulator assembly and a portable refilling hose.

Figure 55—The portable oxygen unit ("walk-around bottle") for use in oxygen demand systems. This cylinder is always painted GREEN.

The regulator also contains a pressure gage, a gripping clamp and a special covered outlet. The pressure gage shows how much oxygen is in the cylinder. When the pressure is less than 100 p.s.i., little oxygen is left and the cylinder must be refilled. The cylinder should be kept charged at all times for ready emergency use. The gripping clamp permits the portable assembly to be readily fastened to the parachute harness or clothing for portability. The special outlet contains a fitting which permits the mask to be plugged directly into the regulator.

The walk-around bottle has another very important application. In case a crew member has to go to the assistance of a fellow crew member, he takes along his walk-around bottle, plugs it into the portable refilling hose at the new station, and leaves it plugged in. This connects him directly to the supply line and, in effect, provides two outlets at every station. If greater mobility is needed, he can connect the wounded crew member to the portable refilling hose and he himself use the regular outlet at the station.

CAUTION.—Extreme caution must be exercised in the use of oxygen equipment to insure that none of it becomes contaminated with oil or grease. Fire or explosion may result when slight traces of oil and grease are in contact with oxygen under pressure. *Be sure that all lines, fittings, instruments, and other items are free from oil, grease and other foreign matter.*

NEVER USE ANY LUBRICANTS IN THE OXYGEN SYSTEM.—There are specific compounds that are approved for use in oxygen systems. Approved antiseize compounds, to prevent galling of aluminum and aluminum alloy threads, and approved sealing compounds, to seal pipe threads are listed in Specification No. 40363. No other compounds should be used.

The "Closed" Oxygen System

The closed rebreathing system for supplying oxygen in aircraft is now under development. The chief advantage claimed for a closed oxygen system is that it will require less oxygen than any other system now in use, provided leaks can be eliminated and nitrogen, carbon dioxide and water vapor can be successfully removed. A diagram of a basic closed oxygen system is seen in figure 56 in which the principle of operation is readily apparent.

LIMITING FACTORS IN OPERATION.—*Oxygen Supply.*—Assuming there are no leaks, the volume of oxygen necessary for operation equals that consumed by the body. Since this rate varies among different individuals and in the same individual under different conditions, such as exercise and cold, there must be a means for regulating the oxygen supply accordingly. One means of accomplishing this is to provide a regulated overflow or leak in the system of such a magnitude that the greatest anticipated need for oxygen can be satisfied by it.

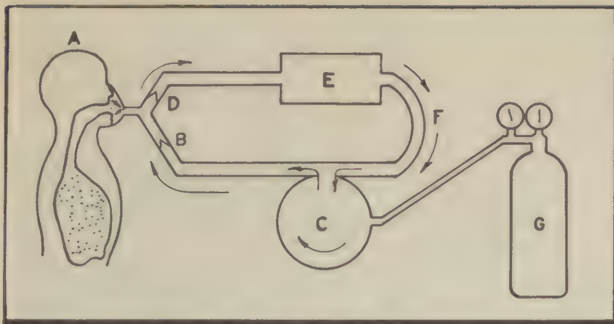


Figure 56—Principles of operation of a simple closed oxygen system. The subject, A, takes a breath, which draws the gas mixture from the reservoir, C, through the one-way valve, B, into his lungs. Upon exhalation, unused oxygen plus carbon dioxide, water vapor, and nitrogen pass through the one-way valve, D, through the purifier, E, which removes the waste products, carbon dioxide, and water. The purified gas thus circulates through the tube, F, to enter the reservoir bag, C, where it mixes with the oxygen which has been admitted from the tank, G, to replace the amount used by the subject. In this illustration the gas is circulated by the subject's own respiratory effort. In some types of closed systems a motor blower or other kind of circulating device is incorporated, and the directional valves, B and D, are omitted. The subject breathes from the circulating stream thus provided.

Purifier.—The waste products are carbon dioxide and water. These are removed by chemical absorbents which must be alkaline (to absorb carbon dioxide) and hygroscopic (to remove water vapor). The life of these absorbents is limited by their capacity to remove the waste products. The chemical absorbent must not offer undue resistance to the free flow of gas by coalescing, nor should it give off caustic droplets or dust.

Cold.—The continued operation of rebreather systems in the extremes of cold which obtain at high altitudes may be affected in two ways: (1) the circulation may be blocked by condensation and freezing of exhaled moisture in the lines or in the absorbing canister and (2) low temperatures may prevent the carbon dioxide absorbent from starting to function or, if it has started, low temperatures may slow up the reaction or completely stop it. Soda lime, for example, will not absorb carbon dioxide in extreme cold; sodium hydroxide will absorb carbon dioxide in the cold, but water vapor will form snow before it reaches the absorbing unit.

In a rebreather system which depends on a continuous valvular overflow for the elimination of nitrogen, the deposition of snow ultimately will obstruct the circulation, reducing the appartus to a continuous-flow system. In such a case, the apparatus will not be able to supply the minute ventilation volume of the user because the flow of oxygen is too small.

The limiting temperature depends on many factors, but apparently any rebreather system is likely to fall below −10° F (roughly, −23° C).

Aircraft Oxygen Cylinders

INTRODUCTION.—Aircraft oxygen cylinders (figure 57) for storing compressed oxygen are included in two general classifications; namely, *high-pressure cylinders* and *low-pressure cylinders*. The *high-pressure cylinder* has a normal working pressure of 1800 p.s.i., whereas the *low-pressure cylinder* has a normal working pressure of 400 p.s.i.

Both high and low-pressure cylinders are made in various sizes and are given type designations as listed at the end of this chapter. The high-pressure cylinders can be easily recognized by their *green* color, whereas the low-pressure cylinders are *yellow* in color. There is one exception to this: the low-pressure type A-4 cylinder (figure 55), used in the portable demand unit, is painted *green*. High-pressure cylinders are fitted with valves, whereas the low-pressure cylinders, which are manifolded in the airplane and are recharged in place, do not have valves. One type of high-pressure cylinder, Specification No. AN-C-51, does not have a valve, since it too is intended for use in a manifolded system with recharging in place.

High-pressure cylinders usually are made of manganese or chrome-alloy steels. They are commonly of seamless construction and are made either by being punched out of a solid billet or by being deep drawn from a flat plate. To make these cylinders shatterproof under gunfire, they are wound with two layers of high-tensile strength piano wire. Since the production sources for this type of cylinder are limited, it has been necessary to develop high-pressure cylinders of welded construction which do not require special and heavy machinery in their fabrication. High-pressure cylinders with spun-in ends also are being used. Several of the cylinders of smaller diameter, both seamless and welded, have been found to pass satisfactorily gunfire tests without the use of the wire winding.

The low-pressure cylinders are made of stainless steel. Types F-1, G-1 and A-4 (figure 57) are made of two deep-drawn cups welded together to form a cylinder. The slender types D-2, F-2 and G-2 (figure 57) are made in three pieces: two end cups and a cylindrical section

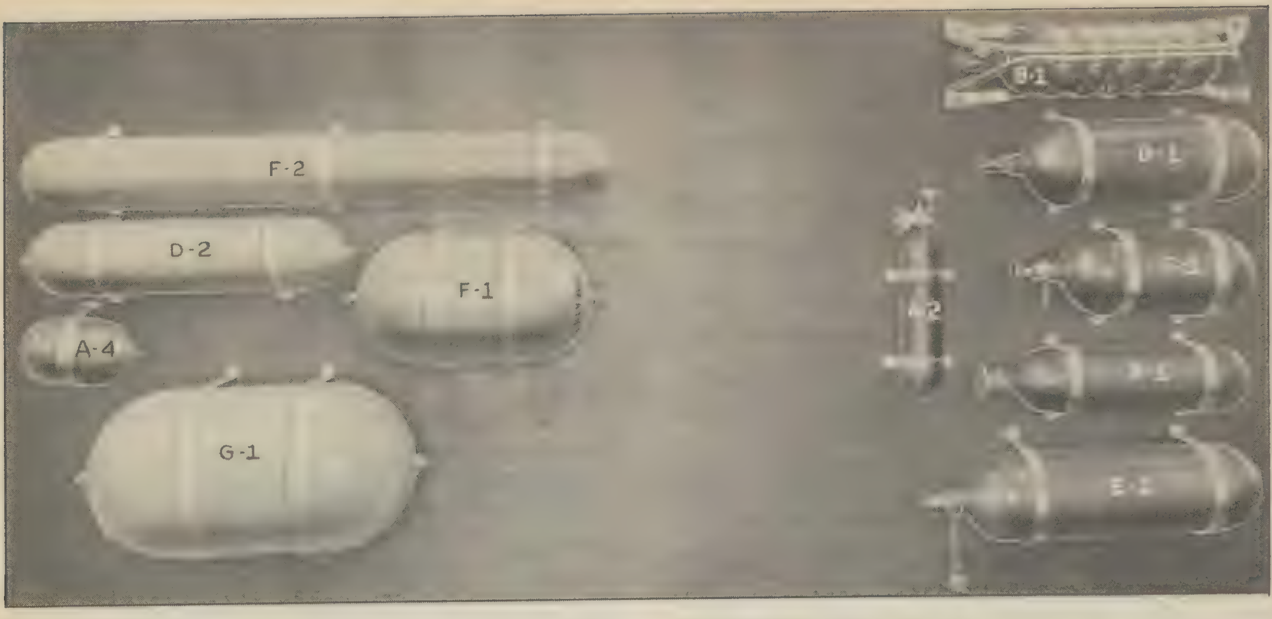


Figure 57—Various types of high-pressure and low-pressure oxygen tanks. All shown here are discussed in the text.

made by rolling up a flat sheet into a cylindrical shape and then welding the longitudinal seam. The cups are then welded on the ends of the cylindrical section to form the complete cylinder. The large type J-1 cylinders used in troop transports are made either by welding together two deep drawn cups or by welding together many smaller sections. The cylinders are provided with 1/4-inch internal pipe-thread spuds at each end to facilitate installation and plumbing. The type A-4 cylinder, however, has only one spud since it is only used with the type A-13 demand regulator as a portable unit by screwing the two together (figure 55). These cylinders are reinforced with bands so as to make them shatterproof under gunfire. In order to eliminate the use of stainless steel, low-pressure cylinders made of low-alloy steels have been developed. Low-pressure cylinders made of these lower grade steels have successfully withstood gunfire tests without the use of reinforcing bands.

In the standard oxygen system in Army Air Forces aircraft low-pressure oxygen cylinders are utilized. In the older type systems, no longer standard, high-pressure cylinders were used. Although several of the older type airplanes still have high-pressure cylinders, most current airplanes are, and all contemplated airplanes will be, provided with low-pressure cylinders. This change from high to low pressure was made by the Army Air Forces after much consideration. Much study and testing have proved low pressure to be superior on most essential points.

Since the high-pressure cylinder carries four and a half times the *pressure* of the low-pressure cylinder, the low-pressure cylinder must necessarily be four and a half times larger in *volume* to have the same *capacity* of oxygen. This larger bulk is the main disadvantage of the low-pressure cylinder, since it is more difficult to find stowage space in the airplane and it offers a greater target area to gunfire than does the smaller high-pressure cylinder. This disadvantage, however, has been appreciably reduced by the use of the long slender types D-2, F-2 and G-2 cylinders (figure 57). These cylinders can be readily installed and offer a small target area from the rear when they are installed lengthwise in the airplane. Many more low-pressure cylinders are used than would be required if a high-pressure system were used so that the oxygen supply is broken down into many small-capacity units, which results in the loss of only a small percentage of the oxygen supply when several cylinders are punctured by gunfire. The bulkier types F-1 and G-1 cylinders (figure 57) also have been satisfactorily installed in most current aircraft.

The low-pressure cylinders have definite advantages in production facilities, rates of production, servicing, safety under gunfire, installation facilities, weight, plumbing and simplicity of installation. The two most important considerations that resulted in the adoption of low-pressure cylinders by the Army Air Forces are servicing and safety under gunfire. Comparisons of high and low-pressure cylinders in regard to servicing and gunfire will be considered next.

COMPARISON.—SERVICING AND RESISTANCE TO GUNFIRE, HIGH-PRESSURE VERSUS LOW-PRESSURE CYLINDERS: *Servicing of High Pressure Cylinders.*—The very first difficulty encountered is in the servicing or recharging of the high-pressure cylinders. The usual practice is to install these cylinders in the airplanes so that they are removable for filling. These cylinders when nearly empty are removed from the airplane and replaced with a full cylinder. The near-empty cylinder is then taken to a filling place, where it is charged with oxygen to a pressure of 1,800 pounds per square inch, directly from commercial type 220 cubic foot oxygen storage cylinders. Inasmuch as these commercial type cylinders are charged only to pressures normally of about 1,800 to 2,000 pounds per square inch, the filling process is not a simple matter.

The common method used in filling is the cascade type. In this process, several commercial type storage cylinders are used, the pressures of which may be anywhere from 500 to 2,000 pounds per square inch. The aircraft cylinder is recharged from the several storage cylinders by starting the charge from the cylinder with the lowest pressure and then using the other cylinders successively. In this manner, by successively equalizing pressures, the aircraft cylinder is brought up to full pressure when the final 2,000 p.s.i. storage cylinder is used. Due to the heat of compression, the aircraft cylinders must be placed in a bath of cold water to insure that a normal charge of 1,800 pounds per square inch is obtained. These cylinders are then returned to the flying line, where they will be ready for use. Another method of filling high-pressure aircraft cylinders is use of an oxygen compressor. This method is more efficient in that it expedites the filling operation and does not require a fully charged storage cylinder to provide the necessary normal charge of 1,800 p.s.i. These methods of filling cylinders are not only tedious, but also entail a waste of time in moving the aircraft cylinders from the flying line to the filling station and then back to the flying line.

To simplify the filling procedure, high-pressure cylinders can be permanently installed in the airplane and manifolded so that they can be filled from a common filler valve in the airplane. This involves the use of a charging cart which is heavy, and requires the use of a vehicle to tow the cart around. The cascade method of filling is used, or the cart may be equipped with an oxygen compressor which makes it still heavier. Due to the heat of compression, the cylinders must be overcharged to insure a full charge after they cool down. If they are not overcharged, an extra charge is necessary, after cooling, to bring the charge to full pressure.

Servicing of the high-pressure system requires heavy and complicated units, special high-pressure regulators, gages, valves and bases and a prime mover to move the cart about. Suitable light and high-capacity compressors that would make the recharging more efficient are not yet available. The complete high-pressure servicing carts are expensive and limited in production rate. Many of these units are required properly to meet the needs of a combat base.

Gunfire and High-Pressure Cylinders.—A second disadvantage of high-pressure oxygen cylinders is their behavior under gunfire. When any high-pressure oxygen cylinder, charged with oxygen, is punctured by a .30 caliber bullet, the steel around the entrance hole burns in the oxygen atmosphere, producing an extremely hot, long flame of short duration. This flame certainly constitutes a hazard. When the old type, nonreinforced high-pressure oxygen cylinder is struck with a .50 caliber bullet, the cylinder explodes or shatters into several parts with great violence and is capable of completely disabling an airplane. A cylinder of this type was placed in the tail of an old pursuit airplane and was hit with a .50 caliber bullet. The resulting explosion took off the entire tail of the airplane.

It was therefore found necessary to reinforce these cylinders properly. A method has been devised to prevent the high-pressure cylinder from exploding, although not from burning, by winding two layers of high-tensile piano wire around the cylinder. After the problem of explosion was solved, a bracket was designed to hold the cylinder and prevent it from "rocketing" when shot. Although the bracket will hold the cylinder, the structure of the airplane must be reinforced so that the bracket will not tear away from its mount. Even though it is properly mounted, the blast from the cylinder when it is shot may tear open the "skin" of the airplane. Gunfire tests conducted on high-pressure cylinders mounted in airplanes have proved that fires may be readily started in this way. The blast of flame resulting from a high-pressure cylinder that has been struck may cause not only adjacent upholstery and wiring to burn, but even, as actually occurred, upholstery and wiring 6 feet away. If unchecked and allowed to get out of control, the fire may consume the entire structure.

Servicing of Low-Pressure Cylinders.—Low-pressure oxygen cylinders were first developed because with their low working pressure, they could be charged from commercial-type storage cylinders with pressures as low as 500 p.s.i. The cylinders are permanently installed in the airplane and manifolded to a common filler valve placed in some convenient location, usually in the "skin" of the

airplane. To fill them it is necessary only to use a hand-pushed, two-cylinder cart. The cart is brought up to the airplane, plugged into the filler valve and the system is thus charged. The method is very similar to that of refueling of an airplane. To insure a normal charge of 400 pounds per square inch, the cylinders are overcharged approximately 25 p.s.i. to overcome the decrease in pressure after the heat generated by compression in filling has been removed. The equipment used is light, simple, inexpensive, available in large quantities and is easily handled on the flying line.

Gunfire and Low-Pressure Cylinders.—The second reason why low-pressure cylinders were developed and why the change from high-pressure cylinders to low-pressure cylinders became mandatory arose from the results of gunfire tests. The old type low-pressure cylinders when subjected to .30 caliber and .50 caliber bullets proved to be superior to the high-pressure cylinders in that they showed no visible flame of fire on impact of the bullet, showed no burning of the metal at the bullet holes in the cylinder, showed only small tendency to rocket after being struck and did not shatter. However, when the tumbled bullet was introduced into the gunfire tests it was found that the old type low-pressure cylinders would explode, and that they required reinforcing. This was accomplished by seam and spot welding horizontal and vertical bonds on the cylinder. The cylinders thus reinforced satisfactorily withstood gunfire. These cylinders required only a couple of straps to hold them in the airplane, and needed little or no reinforcing of the airplane structure at points at which the cylinders were mounted. Low-pressure cylinders thus satisfactorily withstand gunfire without shattering, do not result in fires in the airplane and do not require any elaborate or extra heavy structure for support.

Aircraft Oxygen Systems

OLD TYPE HIGH-PRESSURE (1,800 p.s.i.) OXYGEN SYSTEM.—This system included high-pressure cylinders, annealed 3/8 by .032 copper tubing and types A-6 or A-8 regulators. Solder-type tube connections were used. In the larger aircraft the cylinders were sometimes manifolded, so that more than one cylinder supplied one station. Occasionally, several regulators were manifolded to a bank of cylinders. It was necessary to remove the cylinders to recharge them. For reasons given elsewhere in this chapter, the Army Air Force abandoned the high-pressure system and adopted the low-pressure system.

EARLIEST LOW-PRESSURE (400 p.s.i.) SYSTEMS.—These systems were manifolded together into one distribution line which ran down the length of the airplane. The type A-9 regulators in the airplane were supplied oxygen from this single distribution line. The cylinders also were manifolded on the filler side to a single filler valve. It was thus possible to recharge the entire system from one filling point without removal of the cylinders. Types F-1 and G-1 cylinders were used, and the tubing was 5/16 by .032 annealed copper or a soft-temper aluminum alloy. Flared-type tube connection fittings were used.

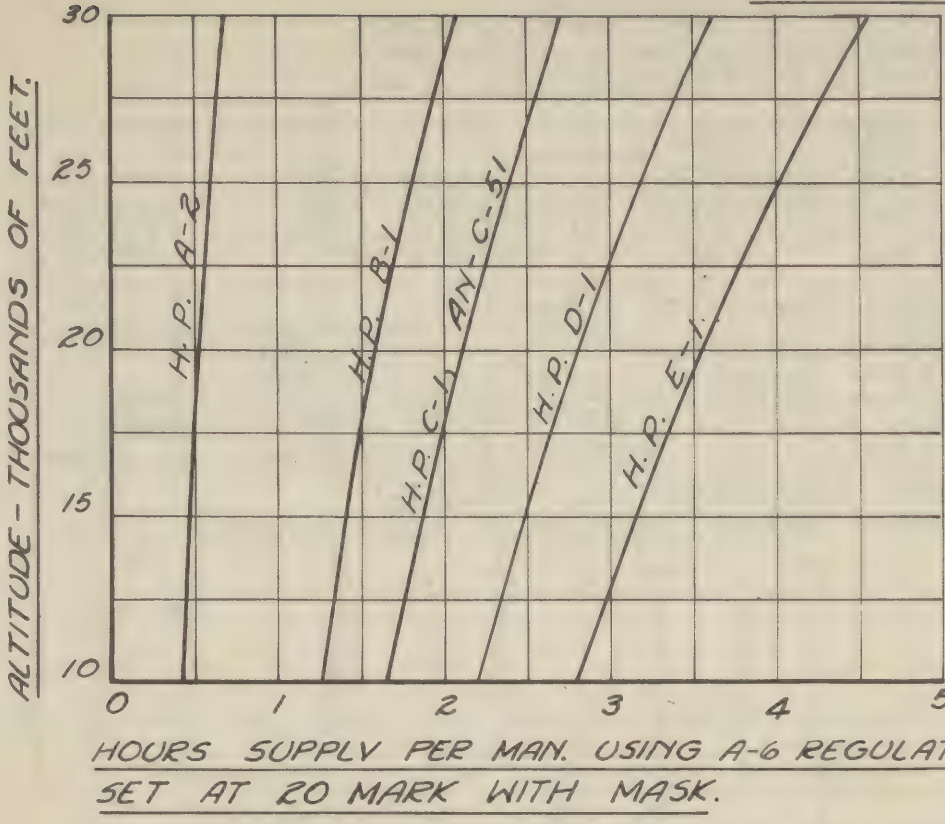
Check Valves.—Check valves were provided for the cylinders, so that in the event any cylinder was punctured by gunfire the entire oxygen supply would not be lost. A pressure relief valve also was provided to prevent the attainment of excessively high pressures due to overcharging or extreme temperatures.

Vulnerability.—This early type of system was simple and easy to install and maintain. However, it was too vulnerable under gunfire. One bullet passing through the common distribution line would result in emtying of the complete system. Although the cylinders were properly check valved, the distribution lines were not. It was therefore necessary to revise this system to provide suitable check valving of the entire system. Results from the actual combat substantiated this revision, since in many cases the distribution lines were being shot away, with the resultant loss of the entire oxygen supply.

The airplane oxygen systems were broken down into several independent systems in a process of revision until at present a completely individual system is supplied for each station. In the meantime the continuous-flow system gave way to the demand system. The same kind of tubing and fittings are retained. The relief valve, however, is no longer considered necessary and is being eliminated.

Duration charts for the various regulators and cylinders used in current aircraft are reproduced in figures 58, 59, 60, and 61.

OXYGEN DURATION



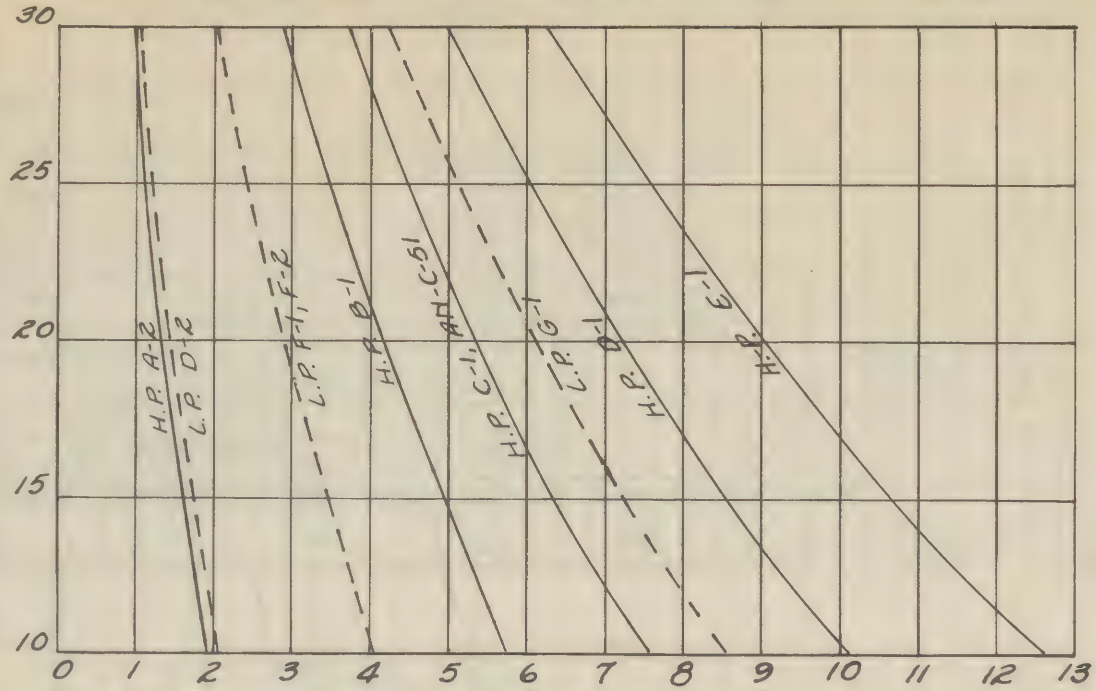
A-6 REGULATOR SET AT 20 MARK USED WITH HIGH PRESSURE CYLINDER. 1800#/□" WORKING PRESSURE		
H. P. CYLINDER	INTERNAL VOLUME (CU. IN.)	FREE GAS CAPACITY 1800-200 #/□" (CU. FT.)
A-2	96	6.4
B-1	295	19.6
C-1 & AN-C-51	386	25.6
D-1	514	34.2
E-1	646	42.9

ALTITUDE (FEET)	FLOW AT ALTITUDE CORRECTED TO SEA LEVEL (LITERS / MIN.)
10,000	7.3 APPROX.
20,000	5.7 APPROX.
30,000	4.5 APPROX.
RATE OF FLOW WITH A-6 REGULATOR SET AT 20 MARK.	

Figure 58—Oxygen supply per man from high-pressure oxygen cylinders, with use of mask and a type A-6 regulator, set at 20 mark. High-pressure cylinders used to 200 p.s.i. minimal pressure.

OXYGEN DURATION

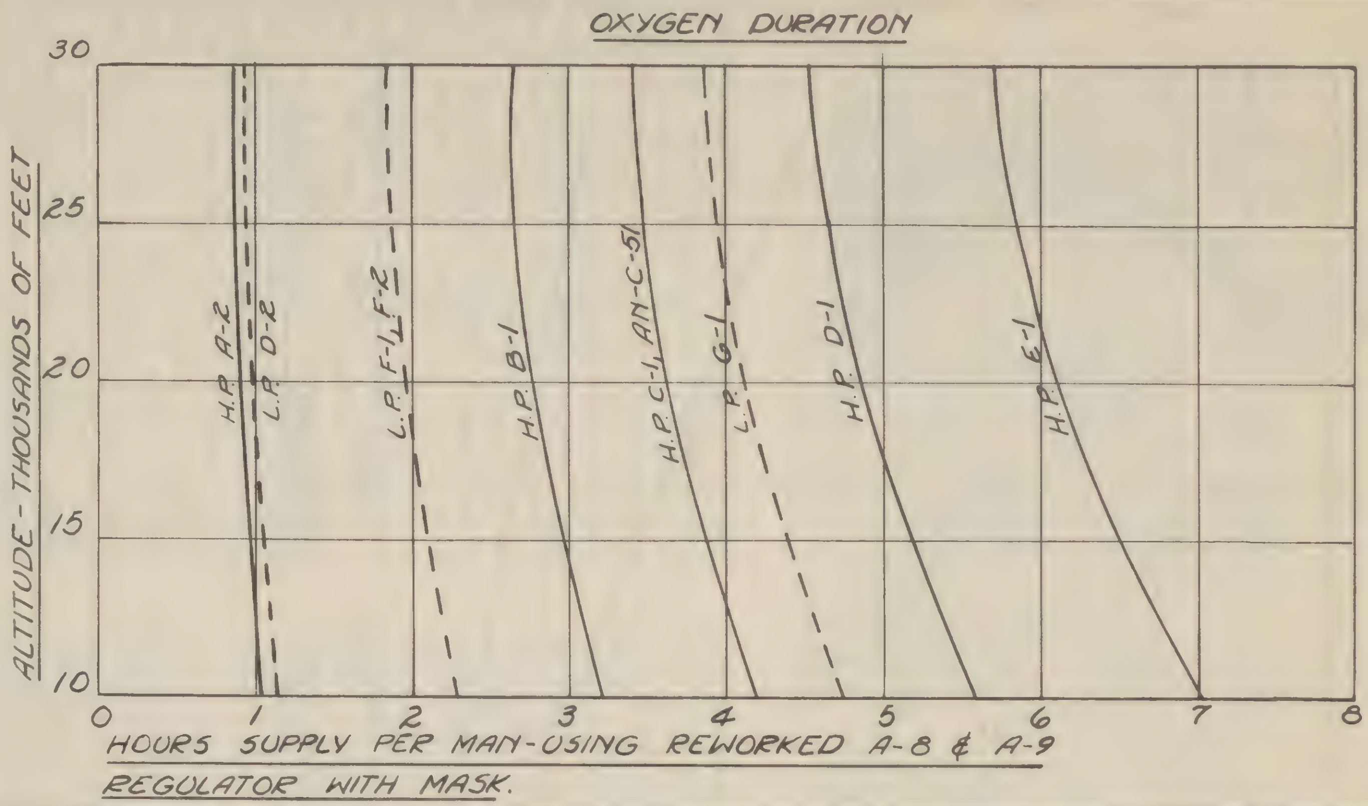
ALTITUDE - THOUSANDS OF FEET.



HOURS SUPPLY PER MAN-USING A-8A & A-9A REGULATOR WITH MASK.
(APPROX. THE SAME FOR A-12 REGULATOR.)

RATES OF FLOW A-8A & A-9A REGULATOR. APPROX. THE SAME FOR A-12 REG.		A-8A REGULATOR USED WITH HIGH PRESSURE CYLINDER. 1800 #/SQ.IN. WORKING PRESSURE.			A-9A REGULATOR USED WITH LOW PRESSURE CYLINDER. 400 #/SQ. IN. WORKING PRESSURE		
ALT. (FEET)	FLOW AT ALTITUDE CORRECTED TO SEA LEVEL. (LITERS / MIN.)	H.P. CYLINDER	INTERNAL VOLUME (CU. IN.)	FREE GAS CAPACITY 1800-200 #/SQ. IN. (CU. FT.)	L.P. CYLINDER	INTERNAL VOLUME (CU. IN.)	FREE GAS CAPACITY 400-50 #/SQ. IN. (CU. FT.)
10,000	1.6 APPROX.	A-2	96	6.4	D-2	500	6.9
20,000	2.2 APPROX.	B-1	295	19.6	F-1 & F-2	1000	13.8
30,000	3.2 APPROX.	C-1 & AN-C-51	386	25.6	G-1	2100	29.0
		D-1	514	34.2			
		E-1	646	42.9			

Figure 59—Oxygen supply per man from high and low-pressure cylinders, with use of mask and types A-8A and A-9A regulators (approximate for type A-12 demand regulator). High-pressure cylinders used to 200 p.s.i. minimal pressure, and low-pressure cylinders used to 50 p.s.i. minimal pressure.



RATE OF FLOW REWORKED A-8 & A-9 REGULATOR	
ALT. (FEET)	FLOW AT ALTITUDE CORRECTED TO SEA LEVEL. (LITERS/MIN.)
10,000	2.9 APPROX.
20,000	3.3 APPROX.
30,000	3.6 APPROX.

REWORKED A-8 REGULATOR USED WITH HIGH PRESSURE CYLINDER. 1800 #/SQ. IN. WORKING PRESSURE		
H.P. CYLINDER	INTERNAL VOLUME (CU. IN.)	FREE GAS CAPACITY 1800-200 #/SQ. IN. (CU. FT.)
A-2	96	6.4
B-1	295	19.6
C-1 & AN-C-51	386	25.6
D-1	514	34.2
E-1	646	42.9

REWORKED A-9 REGULATOR USED WITH LOW PRESSURE CYLINDER 400 #/SQ. IN. WORKING PRESSURE		
L.P. CYLINDER	INTERNAL VOLUME (CU. IN.)	FREE GAS CAPACITY 400-50 #/SQ. IN. (CU. FT.)
D-2	500	6.9
F-1 & F-2	1000	13.8
G-1	2100	29.0

Figure 60—Oxygen supply per man from high and low-pressure cylinders, with use of mask and reworked types A-8 and A-9 regulators.

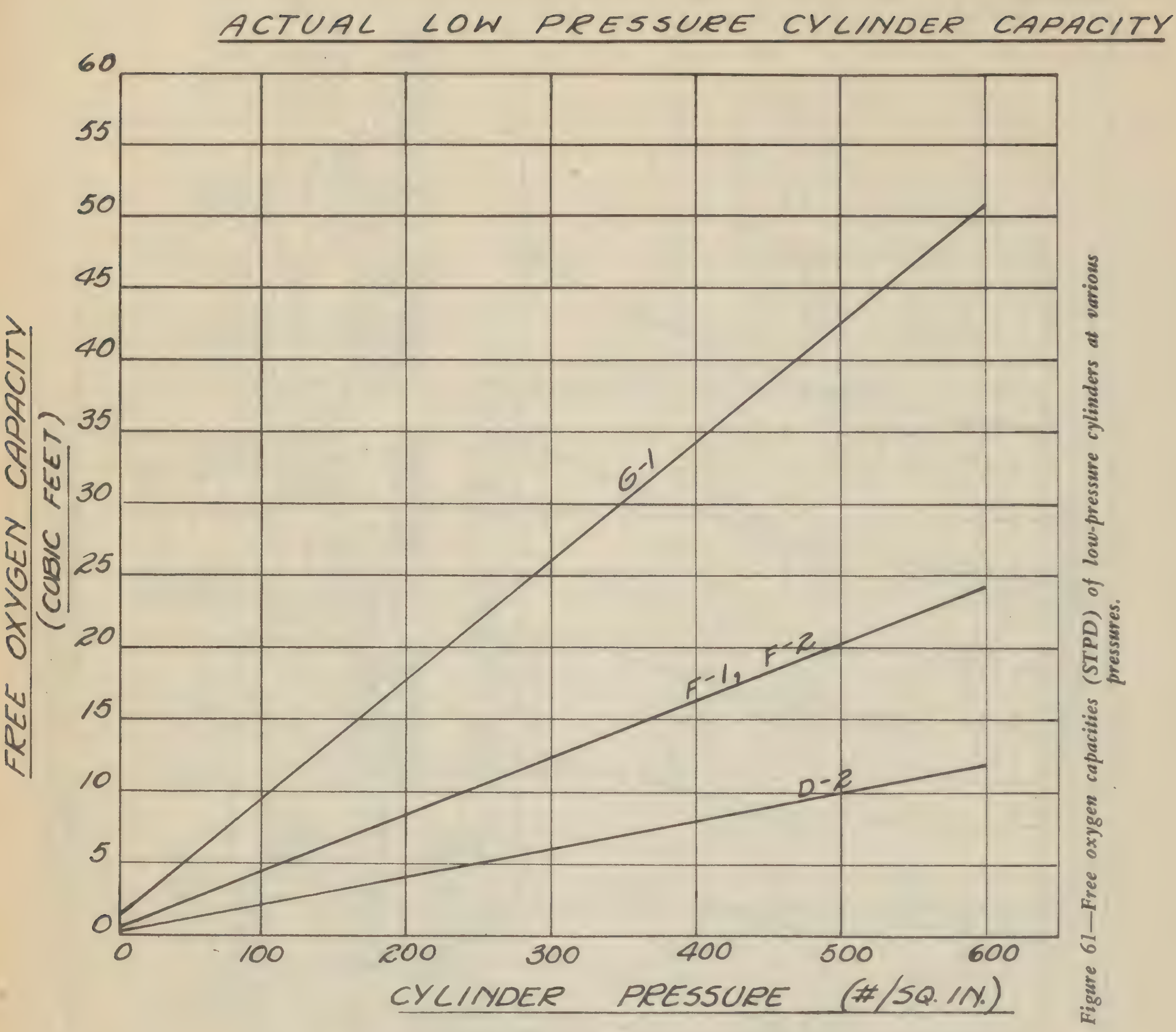


Figure 61—Free oxygen capacities (STPD) of low-pressure cylinders at various pressures.

Graph 4. Free oxygen capacities (STPD) of low pressure cylinders at various pressures.

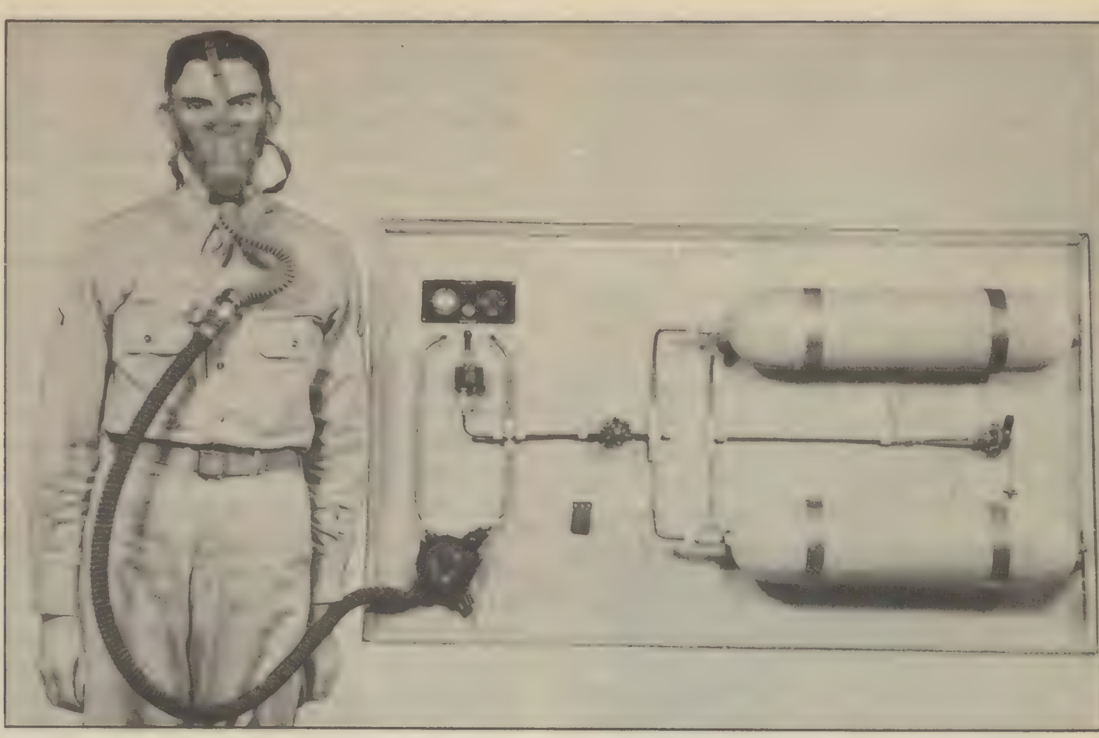


Figure 62—Mock-up of a low-pressure oxygen demand system for pursuit airplanes.

CURRENT ARMY OXYGEN SYSTEM *(Figure 62).* This system was planned in accordance with Army Air Force Specification No. 40363-A. This is an individually manifolded low-pressure demand system. Each station in the airplane is provided with an independent oxygen supply. All the independent oxygen supplies, however, are manifolded on the filler side, so that the entire system can still be recharged from one filler valve. The filler valve usually is located in an oil-proof box, recessed in the "skin" of the airplane, on the left side, and, roughly, amidship. An adapter is provided with the filler valve which enables the filling of the system from British servicing equipment.

Check valves are freely used in the system to make it as little vulnerable to gunfire as possible. The check valves are provided for the cylinders and lines, so that only a small portion of the system will be lost if it is punctured by gunfire. When more than one cylinder is used for a station, two or more lines lead to the station and are connected through a dual check valve situated as close as possible to the demand regulator. In this manner, should one of the lines or cylinders get shot away, there is always an alternate source. The only vulnerable portion of the system is the plumbing beyond the final check valve, and this plumbing is kept to a minimum.

Each station of the airplane is provided with a complete set of demand equipment. This equipment includes the demand regulator with its hose, a flow indicator, a pressure gage and an indicator lamp operated by a pressure signal to warn of a low oxygen supply. Each station also is provided with a portable recharger for refilling the portable walk-around unit that is furnished for each man (figure 55).

The major portion of the current Army Air Forces airplanes use the types F-1 and G-1 cylinders. These cylinders, however, are quickly giving way to the later types D-2, F-2, and G-2. The newer aircraft will be equipped with these cylinders. All tactical and training airplanes have or will soon have the low-pressure demand system.

OXYGEN SYSTEM ON TROOP TRANSPORT AIRPLANES.—The troop transport airplane, however, is one exception and this will have a combination demand and continuous-flow system. The standard demand installation is provided for the crew members, whereas a continuous-flow installation is used for the troops. A central dispensing source of type A-11 automatic continuous-flow regulators provides oxygen to the troop station outlets through a manifolded system. Each troop

station has its outlet, an automatic coupling Part No. 41A6006, to which the type A-8B mask is connected when oxygen is needed. The coupling is opened when the bayonet connection on the mask hose is inserted. The coupling automatically shuts off when the bayonet fitting is removed. One type A-11 regulator is capable of supplying oxygen to fifteen stations, and the rate of oxygen flow varies automatically with altitude.

Both systems in the troop transport airplane are manifolded together on the filler side to one filler valve, so that the entire installation can be recharged from one point. Line valves in the system permit filling the crew system only, or both the crew and the troop system can be filled as need be. For extra long-range flights without troops, the crew can use both supplies through the use of the line valves. The type J-1 cylinder is intended for use in the long-range transport airplanes. Cylinders are removable, so that when only cargo is carried the unnecessary cylinders can be taken out.

PRESSURIZED-CABIN AIRCRAFT.—These aircraft also are provided with the low-pressure oxygen demand system. The installation is primarily for use in emergency, in the event that the cabin pressurizing equipment fails. The oxygen provided is insufficient for the full range of this type of airplane.

SUMMARY.—As larger aircraft and aircraft of longer range are being developed, it is becoming increasingly necessary to provide an oxygen system of reasonable weight and size to meet the advanced performance requirements. The present system cannot efficiently meet these requirements, since the number of cylinders needed becomes excessive. This problem is being met by the development of lightweight aircraft oxygen generators and efficient liquid oxygen systems.

Portable Oxygen Equipment

CONTINUOUS-FLOW PORTABLE UNIT.—The only currently available continuous-flow portable unit is of the high-pressure type. It consists of a type A-8A regulator mounted directly on a type A-2 cylinder which is carried in a canvas sack. This unit, Part No. 41G2437, is tied to the user with straps that are on the sack. The cylinder is of the nonshatterable type, with a wire-wound, seamless or chrome-alloy (or manganese) cylinder, or the latest welded type of stainless steel cylinder. To use it, the crew member, while holding his breath, disconnects his type A-8 series mask from the airplane regulator and connects directly to the portable unit regulator and turns the flow on. This unit has a duration of about one hour at an altitude of 30,000 feet. It is used with either the low or high pressure continuous-flow system, and the type A-9A or type A-8A regulator is employed. This unit cannot be recharged in the airplane, and requires recharging directly from a commercial-type ground storage cylinder.

PORTABLE DEMAND UNIT.—The latest portable equipment (figure 55), Part No. 42D5357, is a low-pressure demand unit. It consists of the non-shatterable type A-4 cylinder and the type A-13 demand regulator. The regulator has a spring clip, so that the unit can be attached to the user's flying clothing or to the parachute harness. To use this portable unit, the user disconnects his mask from the hose on the airplane demand regulator and connects directly to the portable unit regulator. No further manipulation is necessary, since the oxygen will flow automatically with each inhalation. The duration of the supply of oxygen in this unit is low, being in the order of four to eight minutes, depending on activity and altitude. This unit can be recharged in the airplane, however, by the portable recharger, Part No. 42D7261, which is located at each station. The recharger is a two-foot length of flexible hose with a low-pressure filler valve at one end. The other end is connected to the oxygen supply line of the airplane. The A-13 regulator includes a filler valve adapter and a check valve. The cylinder is filled by connecting the adapter to the recharger filler valve. When it is disconnected, the check valve in the regulator and a similar check valve in the filler valve automatically shut off, preventing loss of oxygen from the portable unit or from the recharger. A small pressure gage on the A-13 regulator indicates the pressure in the cylinder. This portable unit is used only with the high- or low-pressure demand system. The high-pressure system, however, must have a pressure reducer that reduces the pressure of 1,800 pounds per square inch to a pressure of 400 pounds per square inch. The portable recharger is connected into that portion of the system which contains the oxygen under low pressure.

Servicing Ground Equipment

At present there is available for charging cylinders without removal of them from the airplane the following equipment.

RECHARGER, AIRCRAFT OXYGEN CYLINDERS.—This is Part No. 42G5917 (figure 63) in accordance with Army Air Forces Specification No. 40327. This recharger is a small two-wheel tubular handcart carrying two commercial-type oxygen storage cylinders of 220 cubic feet capacity, filled with oxygen in accordance with Army Air Forces Specification No. 2198-A, manifolded together through an oxygen puri-

fier (Type A-3) to a pressure-reducing regulator having both a high-pressure gage and a low-pressure gage. A length of flexible hose, with a shut-off valve and filler adapter, is used to make the connection with the airplane oxygen system.

Operation of This Recharger.—To operate:

1. Place two oxygen cylinders in position and attach to fittings on cart.

2. Open the cylinder valve on one cylinder after making sure that the pressure regulator is closed. All fittings and connections should be inspected for leakage.

3. Securely insert adapter end of hose into filler valve in airplane. Connection to a filler valve is made by pushing adapter until it snaps in place.

4. Open shut-off valve on end of flexible filler hose. Start filling the aircraft system by slowly increasing the pressure with the pressure regulator and charging up to approximately 425 pounds per square inch, as shown on regulator gage.

5. When the regulator gage gives a constant reading of approximately 425 pounds per square inch, completely close the pressure regulator. Close the shut-off valve and disconnect. The filler valve is disconnected by tripping the handle (or outer collar) clockwise about one-eighth of a turn. Since pressure will blow the adapter out, securely hold the end of the hose near the shut-off valve before tripping handle.

6. The airplane oxygen cylinders will become rather warm when charged. After cylinders cool to normal temperature, pressure in the aircraft system will decrease 20 to 30 pounds per square inch. After about one hour, pressure in the aircraft system will be approximately 400 pounds per square inch, depending upon initial charging pressure and atmospheric temperature.

7. When the high-pressure supply gage reads approximately 200 to 300 pounds per square inch, close this cylinder and replace with a full one at the earliest opportunity. By alternating the cylinders with the lowest pressure reading at the start of the filling of the oxygen system, and then switching to the other cylinder when necessary to bring the pressure in the aircraft system up to 450 pounds per square inch, considerable economy of oxygen can be effected. When a heavy bomber is filled, it is advisable to have two full cylinders of oxygen on the recharger.

The operation of charging up an airplane with oxygen is thus a very simple one.

Four-Cylinder Oxygen Cart Being Developed.—Also under development is a four-cylinder cart which can be readily towed around and which is capable of holding four commercial cylinders and a dryer, containing a suitable drying agent. This cart will have a greater capacity, will be capable of charging up a large bomber with its full requirement of oxygen, and will in the very same operation dry the oxygen, thus still further reducing the danger of freezing of the oxygen equipment.

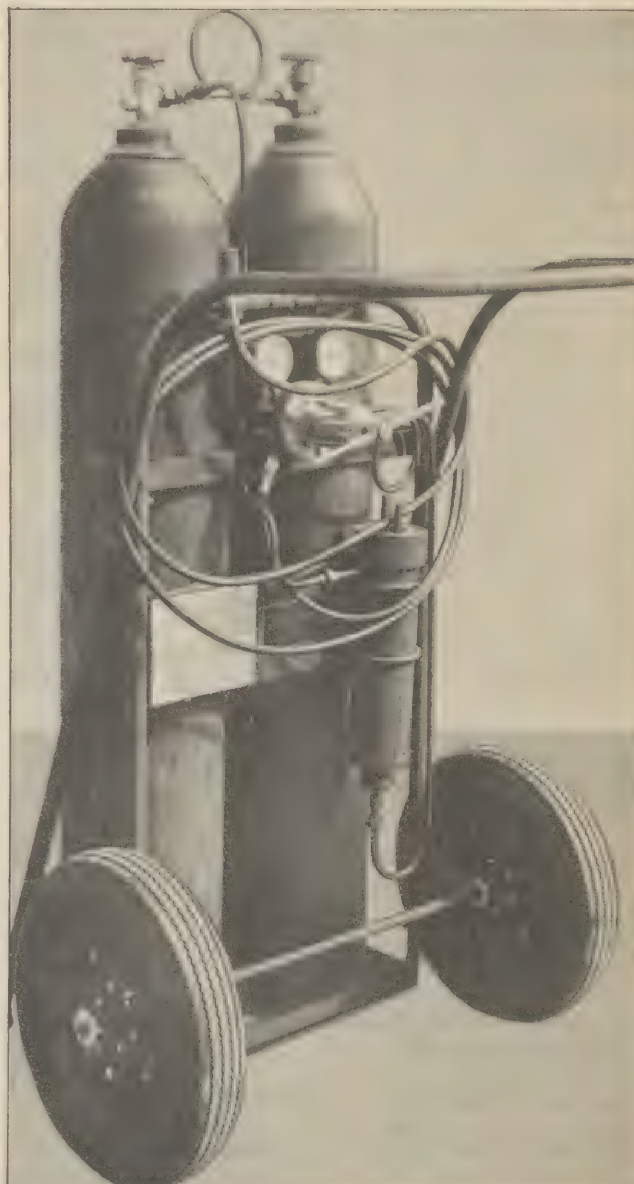


Figure 63—The recharger, aircraft oxygen cylinder part No. 42G5917.

LIST OF OXYGEN EQUIPMENT FOR AIRCRAFT USE

Item	*Specification*	*Drawing No.*	*Status*	*Remarks*
Type A-7 Mask		40G2065	Ltd Std	Nasal rebreather.
Type A-8 Mask	94-3107	40G6471	Ltd Std	Oronasal rebreather.
Type A-8A Mask	94-3107A	41G5658	Ltd Std	Similar to A-8 plus improvements.
Type A-8B Mask	94-3107	42G4764	Ltd Std	Similar to A-8A, but with two valve turrets and microphone provisions.
Type A-9 Mask	3125		Ltd Std	Demand mask.
Type A-10 Mask	3134		Std	Improved demand mask.
AN Standard	AN-M-3	AN-6001	Std	Demand mask.
Type A-6 Regulator	94-40249		Std	High-pressure manual for pipestem.
Type A-8 Regulator	94-40300		Ltd Std	High-pressure manual for mask (continuous flow).
Type A-9 Regulator	94-40319		Ltd Std	Low-pressure manual for mask (continuous flow).
Type A-11 Regulator	94-40334		Std	Low-pressure automatic for mask (Continuous flow.
Type A-12 Regulator	94-40370		Std	Low-pressure demand.
Type A-13 Regulator	94-40382		Std	Low-pressure demand on portable unit.
AN Standard	AN-R-5	AN-6004	Std	Low-pressure demand regulator.
General Cylinder Spec. H.P.	94-40244		Ltd Std	General requirements h-p cylinder.
Type B-1 Cylinder	94-40246		Ltd Std	295 cu in. high pressure.
Type C-1 Cylinder	94-40247		Ltd Std	386 cu in. high pressure.
Type D-1 Cylinder	94-40248		Ltd Std	514 cu. in. high pressure.
Type E-1 Cylinder	94-40251		Ltd Std	646 cu in. high pressure.
Type A-2 Cylinder	94-40302		Ltd Std	96 cu in. high pressure.
AN Standard	AN-C-51	AN-6000-1	Standard	386 cu in. high pressure.
General Cylinder Spec. L.P.	94-40320		Std	General requirements low-pressure cylinders.
Type G-1 Cylinder	94-40321		Std	2100 cu in. low pressure.
Type F-1 Cylinder	94-40330		Std	1000 cu in. low pressure.
Type D-2 Cylinder	94-40355		Std	500 cu in. low pressure.
Type F-2 Cylinder	94-40356		Std	1000 cu in. low pressure.
Type G-2 Cylinder	94-40357		Std	2000 cu in. low pressure.
Type A-4 Cylinder	94-40376		Std	104 cu in. low pressure.
Type J-1 Cylinder	40407		Std	18000 cu. in. low pressure.
Filler (L.P.)	40326		Std	Filling point on low pressure system.
Check (L.P.)	40325		Std	Permits flow in one direction only.
Line (L.P.)	40386		Std	Hand shut-off valve.
Recharger Aircraft (cylinder)	40327	40G8548	Std	Low-pressure aircraft cylinder recharging chart.
Flow Indicator A-1	40389		Std	Bouncing ball type.
Flow Indicator A-3	40427		Std	Blinking eye type.
Pressure Gage K-1 (L.P.)	27368		Std	Pressure gage for low-pressure system.
Signal Assembly (L.P.) (G-1)	32376		Std	Lights lamp at predetermined minimum supply pressure.
Indicator Lamp Assembly		42B3593		Warning light indicates minimum supply pressure.
Hose Assembly (L.P.)	26579	42D6957	Std	Used in portable recharger.
Hose Assembly (H.P.)	26576	45D19277	Std	Used in recharger cart.
Port. Breathing O_2 (H.P. Continuous Flow)		41G2437	Std	Continuous flow walk-around unit.
Port. Oxygen Unit (L.P. Demand)		42D5357	Std	Low-pressure demand walk-around unit.
Port. Recharger Assembly		42D7261	Std	For recharging L.P. demand portable unit.
Auto. O_2 Coupling		41A6006	Std	Used with A-11 regulator in troop transport.
Hose (Mask to Regulator)	40387		Std	Attached to A-12 regulator and includes connection for attachment of mask.
Meter, Ground Flow Check	40400	41A2988	Std	Used to check flows from A-8 and A-9 regulators.
Purifier O_2 A-2	94-40266	37G4082	Ltd Std	Oxygen dryers used at depots.
Purifier O_2 A-3	40352	542D13981	Std	Oxygen dryer used on low-pressure recharging cart.

List of Oxygen Equipment for Aircraft Use (Cont)

Item	*Specification*	*Drawing No.*	*Status*	*Remarks*
Adapter—Army or Navy to British oxygen union		AN6005	Std	For recharging Army or Navy h-p cylinders from British servicing equipment.
Adapter—British to Army or Navy oxygen union		AN6006	Std	For recharging British h-p cylinders for Army or Navy servicing equipment.
Adapter—Navy to Army oxygen union		AN6007	Std	For recharging Navy h-p cylinders for Army servicing equipment.
Adapter—Army to British low pressure oxygen		42A6950	Std	For recharging Army l-p system from British service equipment.
Bracket—High pressure Oxygen Cylinder	AN-B-6	AN6008	Std	Bracket for retaining high-pressure cylinder.
Adapter—Army mask to British outlet		43B13342	Std	For using type A-8 series masks with British MK III series outlets.
Shield—Mask turret adapter		43B8375	Std	For use with type A-8 series masks to prevent freezing of sponge rubber valve and also in converting to demand mask.

CHAPTER XIV
RATIONS AND WATER

Standard Rations

INTRODUCTION.—Numerous factors must be taken into consideration in studying the food and water requirements of flying personnel during military missions. In addition to the necessary caloric content of the food and its proper content of the various food essentials, attention must be given to other factors. Some of these are highly important under conditions of combat, and may even determine the success or failure of a military mission.

CALORIC REQUIREMENTS.—The actual physical work required of flight personnel, even when they are engaged in combat duty, is only light or moderate. Their expenditure of energy is, accordingly, not particularly high under ordinary circumstances. A daily intake of 3,000 calories is considered adequate for an average-sized man under such conditions. Factors which may be encountered in combat, such as psychologic strain and low temperatures, impose additional caloric demands, however, and should be evaluated in the planning of menus for flyers on combat duty.

OTHER FACTORS.—In flight missions which require six to eight hours or longer, it is of great strategic importance to maintain the morale of the crew. Tasty, substantial meals which provide a feeling of satiety are of importance in this respect. In addition, it is desirable that the food be prepared and served hot by members of the crew, provided aircraft facilities permit. These requirements are now met by the "combat lunches" which are available for bomber crews, and which can be prepared in the electrically heated galley kits which are now being installed.

The food, in addition to being appetizing, should contain adequate proportions of proteins, carbohydrates, and fats. In the preparation of diets for missions of short duration no particular attention need be given to the vitamin content, unless the personnel are to be required to eat the same diets frequently.

It is of paramount importance that foods be avoided which are conducive to the formation of gas in the stomach and intestines. As was pointed out in Chapter V, intestinal gases expand with increasing altitude, and the resultant discomfort may be of such magnitude as to be incapacitating. Certain foods, such as beans and cabbage, and carbonated beverages, are notorious for their gas-producing qualities. Flatulence is largely a matter of individual reaction, however, for many foods which are well tolerated by some individuals result in gaseous distress to others. Most people know by experience what particular foods result in flatulence; hence, these foods should be avoided before and during flights.

EMERGENCY RATIONS.—Provisions also must be made, in the form of emergency rations, for the sustenance of the crew, should forced landings in desolate areas occur. Several types of concentrated rations have been prepared and tested, but none has yet proved completely satisfactory. Perhaps the best of the emergency rations now available is the type K field ration, a three-meal package of which contains slightly more than 3,000 calories, but which has the disadvantage of being fairly bulky. The K ration also gives promise of providing a satisfactory meal for use by fighter pilots during long missions. In the preparation of new emergency rations, it is important that more attention be paid to the factor of palatability, in addition to the theoretic virtues the ration may possess. This has been overlooked in several rations which have been tested recently, with the result that much of the food has gone uneaten.

Normally nourished individuals have an appreciable reserve of body fat. It is not necessary, therefore, to supply the entire caloric requirement of the individual in his emergency ration, for the body fat is readily available for the production of energy. Thus, emergency rations should consist predominantly of carbohydrates and proteins and should have a relatively low content of fat. The total daily caloric value of the ration may safely be as little as a half or even a third of the actual body requirements of the individual who must subsist on this diet for only one or two days, provided his water and salt balance is maintained. For individuals who have been subsisting on an adequate dietary previously, little consideration need be given to the vitamin content of their emergency rations.

Water

On ordinary flight missions, even those of long duration, rarely will more than two quarts of drinking water be required for each member of the crew. This may be carried in individual canteens and in thermos

bottles, for the preparation of hot or cold drinks from the powdered coffee, bouillon, and lemon powder that accompany the rations. After forced descent or bailing out, however, great variation in the water requirement may be encountered, depending on the locality and the amount of work performed by the men in adjusting to their new environment. Unfortunately, marked space restrictions must be met by the emergency water and rations which can be accommodated in parachute packs and emergency life rafts.

In cold humid regions with abundant rainfall, part of the available space may be allotted to concentrated foods such as biscuit and D ration chocolate bar. In the desert and tropics, on the other hand, the requirement for food is insignificant in comparison to the much greater necessity for water. A man can live for only two or three days in intense dry heat without water, but he can go without food for many days. It is obviously desirable, therefore, that military aircraft operating over isolated arid areas carry as much water as allowed by the restrictions of weight and volume. Water is now available in metal cans, which can be stowed in the plane either for transport or emergency use. Canned water is also carried in the emergency life raft. All such water has been boiled before canning and pasteurized afterwards.

It has been recommended on the basis of physiologic tests that water rations be conserved during the first 24 hours. In men in a life raft, doing little work and ingesting no food in a temperate climate, water ingested during this period is probably only wasted via the kidneys, if sensible perspiration is not appreciable. Loss of water through the skin can be kept minimal by keeping the clothing saturated with sea water.

Coconuts have been advocated as an excellent source of water as well as of food for men forced down in a jungle.

Various chemical methods for the bacterial purification of water are now under consideration for use by the Army Air Forces. Some of these, such as chlorination and iodinization, have long been in use, but may be superseded by more effective chemical methods now under investigation. These may be employed alone or in conjunction with various types of filters.

The problem of making sea water potable remains just as challenging today as it was a hundred years ago. Because of its high salinity, magnesium and sulfate content, ocean water can not be drunk with benefit and produces intolerable thirst. Indeed, the drinking of such water is distinctly hazardous. Innumerable chemical methods have been devised for the treatment of sea water under emergency conditions in order to make it potable. Yet none has satisfactorily met the requirements of simplicity, compactness, and a sufficiently high water-chemical ratio. Not all the possibilities of such an attack have yet been exhausted, however, and processes now under development seem to hold promise.

An alternative method for the emergency treatment of sea water is found in the use of stills. Here, too, the size and weight of the unit and the water-fuel ratio are matters of great importance. Stills are being considered for use in the large emergency life rafts, but such stills are yet in the experimental stage.

CHAPTER XV
EMERGENCY EQUIPMENT

INTRODUCTION.—Emergency equipment has been developed to cover the most essential requirements of flyers who may be forced down on water and in an uninhabited area, whether it be the barren tundra of the Arctic North, the desert, or the humid tropics. It is rather obvious that this equipment cannot be complete in every detail because of the weight and volume involved, but rescue equipment has been designed to incorporate the most essential and absolutely necessary items for the maintenance of life for short periods under the inhospitable conditions of desert, jungle, water or arctic wastes.

FIRST-AID EQUIPMENT.—Two distinct types of medical first-aid equipment have been designed and procured in quantity for the use of flying personnel.

First-Aid Kit, Aeronautic.—First-aid kit, aeronautic, has been designed for use in aircraft and is installed on all tactical types of aircraft, roughly on the basis of one kit to each two men. The following items are incorporated in this kit:

1. Dressing, first aid, small (wound dressing).

2. Sulfanilamide powder (for use in dressing).

3. Sulfadiazine ointment (burn ointment).

4. Eye dressing.

5. Tourniquet.

6. Sulfadiazine tablets (to be taken in the event a wound has been sustained).

7. Syrettes morphine tartrate (hypodermic to relieve severe pain).

The external pocket of this kit contains some small adhesive bandages and iodine swabs that have been included in the kit for the care of minor wounds.

First-Aid Kit, Parachute.—The first-aid kit, parachute, is a small compact package that is tied to the parachute harness by means of simple cotton fasteners. This particular kit was designed to insure that the more important first-aid items would always be present and accessible to an aviator in flight, or would be available to him after a parachute escape. This kit can be very simply unfastened from the parachute harness and can be carried either in a small rubber dinghy or in the pocket of the uniform. It contains the following items:

1. Dressing, first aid (wound dressing).

2. Syrettes morphine tartrate (for relief of pain).

3. Tourniquet.

A complete description of the components of these two medical kits is shown in figure 64, where the kits and the various components are illustrated and where the general description of the uses of each item is given.

FLOTATION EQUIPMENT.—The types of flotation equipment carried in aircraft for use in the event of emergency on overwater flights are pneumatic life preserver vests and pneumatic life rafts.

Pneumatic Life Preserver Vests.—The pneumatic life preserver vest, commonly called the "Mae West," has been in service, essentially in its present form, for a number of years and is well known to almost all flying personnel. Army regulations require that this vest be worn by all flying personnel on long overwater flights. Further description of this item is not believed necessary, since it has been commonly used in the service for a number of years.

Pneumatic Life Rafts.—The following types of pneumatic life rafts are in use by the Army Air Forces at present:

1. Type A-2. (1,000-pound capacity).

2. Type A-3. (1,000-pound capacity) (figures 65, 66, and 67).

3. Type B-3. (500-pound capacity).

4. Type B-4. (500-pound capacity).

5. Type C-1. (250-pound capacity).

6. One-man parachute type pneumatic life raft (figures 68, 69, and 70).

The types A-2, B-3, B-4, and C-1 are of an early design and are being superseded by types A-3 and one-man parachute rafts. For airplanes having crews of one, two or three men, the one-man parachute type pneumatic life raft is designed for use by each crew member on overwater flights. On all airplanes having crews of more than three men, the type A-3 raft is used; crews of four and five men have one type A-3 raft; crews of six to twelve men have two type A-3 rafts; crews of twelve to fifteen men have three type A-3 rafts.

Figure 64—The aeromatic first-aid kit and the first-aid kit, parachute.

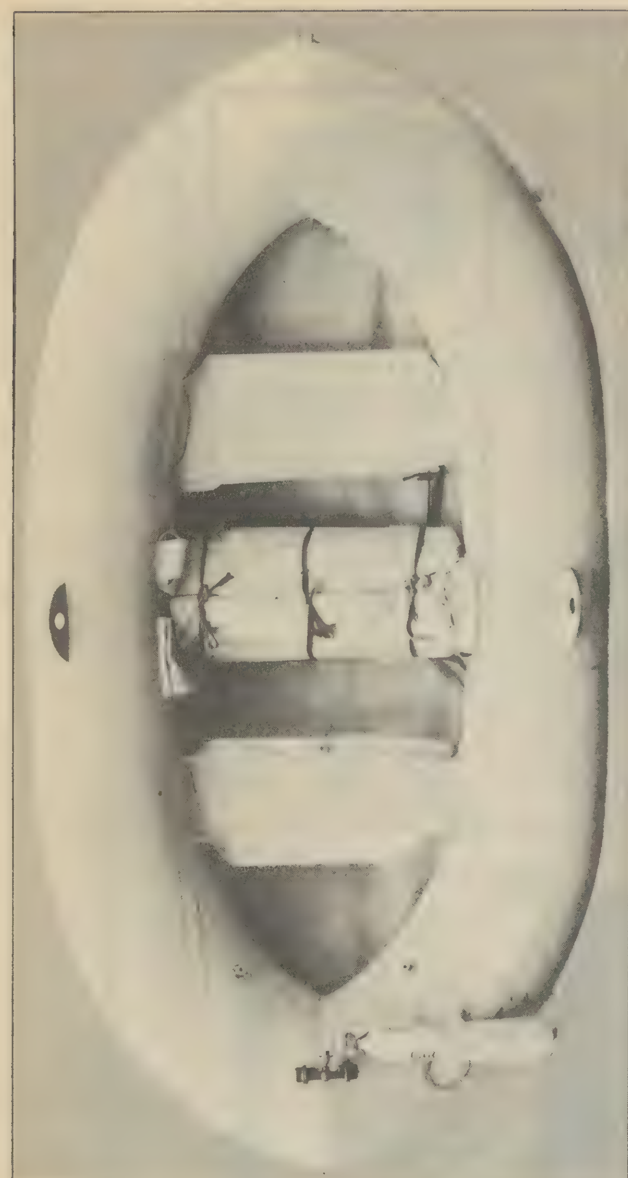


Figure 65—The type A-3 life raft, inflated, as seen from the top.

The one-man parachute type raft is designed for use in conjunction with the seat-type or back-type parachutes. When it is used on the seat-type parachute (figure 69), the pack replaces the standard parachute cushion. In this case, the side straps can be either tied to the parachute harness or folded between the pack and the parachute. The four corners of the raft pack are secured to the seat parachute pack at the same points at which the seat cushion was secured. The attachment cord which protrudes from the right-hand corner of the raft pack is attached to the D-ring of the left side of the vest after the cord has been threaded underneath the harness of the parachute. In other words, the attachment cord is located between the parachute harness and the pilot. Prior to landing in water, the pilot will inflate one carbon dioxide cylinder of his life preserver vest by pulling one of the pull cords of the vest. This will provide sufficient buoyancy to bring the pilot immediately to the surface of the water. The breast strap and leg straps of the parachute harness are released either before he strikes the water or when he comes to the surface. The raft pack is pulled to the pilot and the top of the raft pack is jerked open by his pulling the right-hand strap provided for this purpose on the top of the raft pack. The attachment cord is attached to the valve of the raft carbon dioxide infiltration cylinder and, therefore, can be quickly reached by the pilot's pulling the cord to him. The safety pin of the carbon dioxide valve is released and the valve handle is opened. This will automatically inflate the raft within a few seconds. The pilot then enters the smaller end of the raft by grasping the hand straps nearest to him and giving a quick flip of his body into the raft. The pilot will sit with his back to the larger end of the raft. A sea anchor is provided which can be lowered into the water and tied to a handle of the raft to prevent drift. A bailing cup will be found with the sea anchor; this cup can be readily detached for bailing purposes. Two hand paddles are provided. The most restful position for paddling will be that in which the arms are rested on the inflation tube, with the man paddling backward. Inside the accessories case a first-aid kit is provided for treatment of wounds. One can of drinking water is provided. One can of fluorescein dye is provided; the dye can be shaken over the surface of the water as a distress signal marker. Care should be taken to inspect the raft for leaks. Patching material is provided in the accessories container for the repair of leaks, and two bullet-hole plugs also are provided for screwing into bullet holes in the raft. A waterproof cloth, orange-yellow on one side and blue-green on the other, is provided. This cover can be used as a shade cloth, water-catching cloth, signal cloth, sail or camouflage cover. The initial inflation with carbon dioxide gas may gradually permeate the inflation tube. The raft should be "topped off" occasionally by use of the mouth inflation tube provided for this purpose. The mattress valve should be unscrewed one or two turns for the oral inflation, and then tightened up again.

The type A-3 five-man pneumatic life raft is designed for stowage in raft compartments of airplanes. The airplane compartment is arranged for automatic inflation

Figure 66—Accessories which accompany the type A-3 life raft, complete with radio.

and ejection of the raft by means of control cables or handle releases located both inside and outside the airplane. The control cable first releases the raft compartment door latch and then actuates the pull cord on the carbon dioxide inflation cylinder. Inflation of the raft effects ejection of it from the compartment. A stowage rope secured to the airplane and to the raft by means of a snap-hook will keep the raft from drifting away. This stowage rope has a breaking strength of 75 to 100 pounds, so that the cord will break before the raft is pulled under the surface of the water in cases in which the airplane sinks immediately. In cases in which the raft is carried in the airplane as a separate unit, the raft is packed in a carrying case. In such cases, the raft is removed from the carrying case and inflated manually by pulling on the carbon dioxide cylinder-valve release cord. Each raft should have the following accessories:

a. One pyrotechnic pistol and six distress signals installed and sealed, waterproof, in the emergency signal kit furnished by the raft manufacturer.

b. Seven emergency drinking water cans, containing 12 ounces of water.

c. Three sea markers.

d. Three K rations (nine packages).

e. One flashlight.

f. One scout knife.

g. One police knife.

h. One first-aid kit.

i. Two emergency fishing kits.

j. One shade and camouflage cloth.

k. One combination water-catching, signal, and sail cloth.

l. Two oars.

m. One hand pump, complete with hose.

n. One repair kit.

o. One bailing bucket.

p. Four bullet-hole plugs.

q. Forty feet of 75-pound cotton cord.

The scout knife, police whistle, 40 feet of cord, bailing bucket, and repair kit are located in the central accessories pocket of the raft. All other accessories except the oars are inside the accessories container. The oars shall be placed in the pockets of the accessories container. The accessories container is sealed, tied securely, and then tied to four loops on the bottom center of the raft. A radio, complete with accessory equipment furnished by the Government, also shall be packed inside

Figure 67—The accessory case of the type A-3 life raft as packed with radio, viewed from the side.

Figure 68—The one-man pneumatic life raft pack as fitted to a back type of parachute. It is attached outside the harness.

Figure 69—The one-man pneumatic life raft pack as fitted to a seat-type parachute, front view.

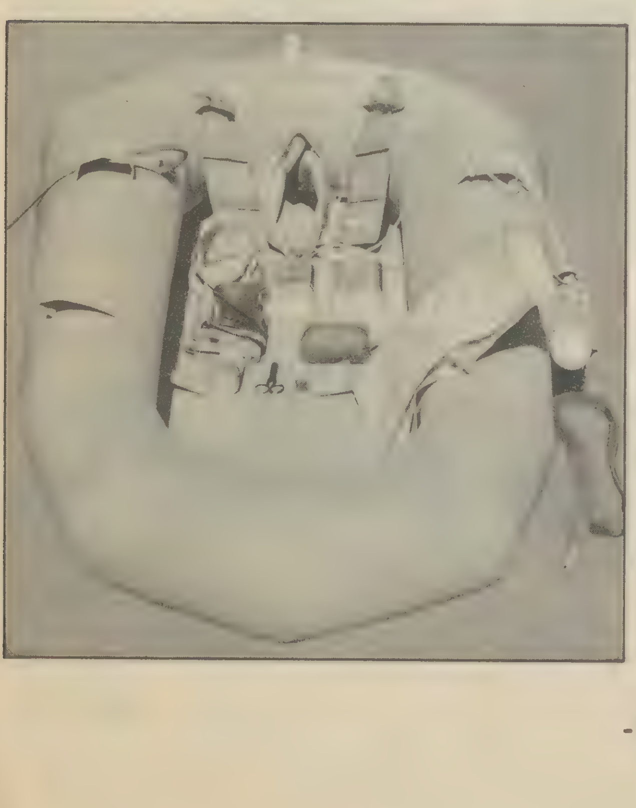


Figure 70—The one-man pneumatic life raft, inflated, with the accessories unpacked.

the accessories container when specific instructions are given to include radio equipment. While men are in the raft on the water, all accessories not in use should remain securely tied up or fastened inside the accessories pockets on the raft, and all accessories in actual use should be anchored to the raft by tying them with cord provided in the raft. Otherwise, if the raft capsizes, the accessories will be lost. Every crew member, before starting on an overwater flight, should be thoroughly familiar with operation and use of the sea-rescue equipment provided. A thorough inspection of the raft and accessories should be made prior to overnight flights, to see that they are in proper working order.

PARACHUTE EMERGENCY KIT.—Parachute emergency kits were developed to provide certain necessary items for the sustaining of life in the event of emergency parachute descent or forced landing in isolated territory.

Description.—The parachute emergency (jungle) kit consists of a rectangular kit approximately 13 inches by 15 inches by 3 inches. This kit contains a felt insert in which cut-outs are provided for the carrying of necessary items of equipment, and is enclosed in a zipper fastened canvas cover. A 1-inch thick pad is provided as a cushion for the wearer (figure 71).

Operation.—Upon landing, the flyer opens the kit and removes the necessary items, which he carries on himself or in the kit as a knapsack. The following items are included in each kit:

1. Curved needle with thread: to be used for repair of torn clothing or to improvise a camp, with the parachute as a canopy.

2. Canvas water container: for carrying drinking water.

3. One pair gloves: to provide protection of the hands.

4. Machete: for cutting through jungle and for chopping wood.

5. Signal flares: for signaling rescuing aircraft.

6. Compass: for directional use.

7. Plastic match container: to provide dry matches.

8. Atabrine tablets: two tablets to be taken each week for the prevention of tropical fever (figure 72).

9. Emergency fishing kit: provided to catch fish for food.

10. Mosquito headnet: to provide protection from mosquitoes and small insects.

11. Flat paper cups: for use in scooping water from small streams and for the preparation of hot drinks.

12. Cooking container: for cooking and melting snow in Arctic regions for drinking purposes.

13. Bath soap: as an aid to hygiene and prevention of disease.

14. Shur-lite beacon flare: to be used for starting fires with wet or frozen wood.

15. Snow goggles: for use in Arctic regions.

16. Pocket knife: for general utility.

17. Emergency ration: food.

18. Tourniquet: to stop circulation in case of wound or injury.

19. Iodine swabs: for cuts and scratches.

20. Sulfanilamide powder: for use on open wounds.

21. Salt tablets: to prevent heat prostration in hot climates.

22. Halazone tablets: for purification of water.

23. Individual dressing pockets: for dressing wounds or injuries.

24. Band-aid: for dressing small cuts or wounds.

25. Sulfadiazine ointment: for the treatment of burns.

26. Sulfadiazine tablets: to be taken internally in case of severe wounds or injuries.

In addition to the above items, a caliber .45 automatic pistol and extra ammunition should be carried. The parachute canopy should be cut into strips to provide wrapped leggings.

Installation.—Parachute emergency kits can be used with either seat-type or back-type parachutes. For use with seat-type parachutes, the conventional back pad is removed and the emergency kit is attached by means of fittings provided. When the kit is used with a back-type parachute, the tapes provided are tied securely through the loops formed at the bottom of the lift webs.

Maintenance.—Parachute emergency kits should be inspected frequently to insure that all necessary items are present and in good condition.

EMERGENCY SUSTENANCE KIT.—The emergency sustenance kits, types E-1, E-2, and E-3, are on limited standard and have hence been procured in small numbers. Future requirements will have to determine the success and usefulness of these items.

Figure 71—The type B-3 emergency jungle kit, open.

The emergency sustenance kit, type E-1, is packed in a fiberpax drum and contains the following equipment.

Emergency Sustenance Kit (type E-1):

Description	*Quantity*
Biscuit, U. S. Army field ration, type C (Loose-Wiles Biscuit Co., Chicago, or equal)	4 Cans
Dextrose Energy Tablets, 24 tablets per roll (Curtiss Candy Co., Chicago, or equal)	4 Rolls
Raisins in Sealed 1-lb box	1 Box
Orange Pekoe Tea, approximately 100 bags in $1/2$-lb box	1 Box
Cube sugar in 1-lb. box, sealed in wax paper	1 Box
Rice in 1-lb box	1 Box
Iodized table salt in 1-lb box	1 Box
Powdered milk in 1-lb can ("Soft Kurd" M. and R. Dietetic Laboratories, Inc., Columbus, Ohio, or equal)	1 Can
Corned Beef in 1-lb sealed can	2 Cans
Bacon in 1-lb airtight metal can	1 Can
Sweet chocolate in 1-lb bar, sealed in wax paper	1 Bar
Dried soup in 4-oz can, assorted varieties (Knorrs Food Products, New York, or equal)	4 Cans
Emergency drinking water, Specification No. AN-W-5	4 Cans
Tomato juice in 12- to 16-oz can	4 Cans
Waterproof match box, complete with matches	2 Boxes
Hunting knife, approximately 5 in. long, complete with sheath (Marbles Manufacturing Co. or equal)	2
Mess kits, Boy Scout model	2
Fine mesh mosquito proof head net	2
Canvas gloves treated so as to be water repellent (Sears-Roebuck Catalog No. 33-3882, or equal)	2 Pair
Mosquito repellent (Sho-Fly Cream No. 1485, Pflueger, Columbus, Ohio, or equal)	2

The emergency sustenance kit, type E-2, is contained in a combination stove and container which is intended to be used with the food components of the kit, type E-1, and includes the following items:

Description	*Quantity*
Combination .22 caliber and .410 gage gun (Stevens, or equal)	1
.22 caliber long rifle high-speed ammunition	4 Boxes
.410 gage No. $7\frac{1}{2}$ chilled shot ammunition	3 Boxes
.410 gage slug ammunition, 5 per box	5 Boxes
First-aid kit (Johnson and Johnson "Aero Kit," or equal)	1
Household matches packed in airtight container	1 Box
Camphor	1 Tube
Generator operated flashlight ("Vizlight," or equal)	1
Carborundum whetstone, approximately 4 in. long	1
Wax candles approximately $1\frac{1}{4}$ by 5 in.	2
Frying pan with folding handle, approximately 8 by $1\frac{1}{2}$ in.	1
Stew pan, approximately 8 by $6\frac{1}{2}$ in.	1
Large spoons	2
Butcher knife, 10-in. blade	1
Corn or cotton seed cooking oil	1 Pint
Machete in accordance with Drawing No. 42D7462	1
3 prong fish hooks	3
Salmon eggs	1 Jar
Medium weight enameled fish line, 25 yds per roll	1 Roll
3 foot, 15-lb gut leaders	3

Description	*Quantity*
Snelled flies No. 8 hook, assorted patterns	6
Snelled hooks, assorted sizes	24
Lead sinkers, approximately 1/8 oz	6

The emergency sustenance kit, type E-3, was designed to be stuck in the clothing of an aviator and is packed in a cloth bag approximately 12 inches long and 6 inches wide. It is contemplated that this bag would act as a water receptacle when the kit is used. This kit contains the following items:

Description	*Quantity*
Safety matches	1 Box
Pocket compass	1
Hack saw blade (maximum length, 6 in.	1
Halazone tablets	12
Benzedrine tablets	6
U. S. Army field ration "D" (approximately 4 x 2 1/4 x 7/8 in.)	1
Package of 15 flavored dextrose tablets (6 lemon, 9 malted milk)	2
Cellophane envelope of instant bouillon powder, 20 grams	1
Chewing gum	1 Stick

The emergency sustenance kit, type E-5, consists of a suitable waterproof container and a number of emergency items for use in over-water flights. It is intended that the kit be dumped overboard and subsequently be picked up from the water, or it can be thrown into the emergency raft at the time it is launched if conditions permit. Its contents are as follows:

Description	*Quantity*
Collapsible bailing bucket	1
Pocket type compass, with hunting case	1
Waterproof match container, complete with Matches	2
Hunting knife, 5 or 6-in. blade with sheath	1
Axe, hand, approximately 3 5/8-in. blade with sheath	1
Minimum reflecting surface mirror, 30 sq in.	1
Large wax candles	2
Beer type can openers	2
Package of fishing tackle containing the following items:	
Hooks, size 7-0	2
Hooks, size 3-0	2
Hooks, size 3	2
Hooks, size 6	2
Sinkers, 2 oz	1
Sinkers, 1 oz	1
Sinkers, No. 2 clinchers	2
Feather jig	1
Line, fishing, 54-lb test	75 Yards
Line, fishing, 25-lb test	50 Feet
Flares, large, signal, hand held color optional	6
Paulin, life raft, utility, Specification No. 26756, size 18	1
Sea marker, Specification M-528	2 Cans
Tomato Juice, 18 to 20 oz cans	10
Emergency drinking water, 20 oz cans	10
Rope, 1/4-in.	40 Feet

It is to be noted that there are numerous types of emergency kits, all of which contain some food components and some emergency gear such as knives, fishing tackle, a compass, etc. In many instances, canned water is included. A review and critical appraisal of all the kits is in progress and it is entirely probable that, in the light of our present combat experience in the various geographic areas of the world, the number of kits standardized and procured will be fewer in number, of greater completeness, and of a greater general usefulness.

MALARIA

Figure 72—Map showing distribution of Malaria in the World.
(U. S. Army Medical Museum.)

APPENDIX I

METRIC EQUIVALENTS

(Bureau of Standards)

LENGTH

cm = .3937 in.	In. = 2.54 cm
Meter = 3.28 ft	Ft = .3048 meter
Meter = 1.094 yd	Yd = .9144 meter
Kilom = .621 mile	Mile = 1.61 Kilom

AREA

Sq cm = 0.1550 sq in.	Sq in. = 6.45 sq cm
Sq m = 10.76 sq yd	Sq ft = .0929 sq m
Sq m = 1.196 sq yd	Sq yd = .836 sq m
Hectare = 2.47 acres	Acre = O.405 hectare
Sq Kilom = .386 sq mile	Sq mile = 2.59 sq kilom

VOLUME

Cu cm = .061 cu in.	Cu in. = 16.38 cu cm
Cu m = 35.315 cu ft	Cu ft = .028 cu m
Cu m = 1.308 cu yd	Cu yd = .7645 cu m

CAPACITY

Liter = .0353 cu ft	Cu ft = 28.32 liters
Liter = .2642 gal. (U. S.)	Gal. = 3.785 Liters
Liter = 61.023 cu in.	Cu in. = .0164 liters

Liter = 2.202 lb of fresh water at 62° F

WEIGHT

Gram = 15.432 grains	Oz = 28.35 gram
Gram = .0353 oz	Lb = .454 kg
Kg = 2.2046 lbs	Ton (sht) = 907.18 kg
Kg = .0011 ton (sht)	Ton (sht) = .907 met. ton
Met. ton = 1.1025 ton (sht)	Ton (sht) = 2000 lbs

Grain = .0648 gram

PRESSURE

1 kg per sq cm = 14.2233 lb per sq in.
1 lb. per sq in = .070307 kg per sq cm.
1 kg per sq m = .20482 lb per sq ft.
1 lb per sq ft = 4.8824 kg per sq m.
1 kg per sq cm = 0.98784 standard atmosphere.
1 standard atmosphere = 1.033228 kg per sq cm.
1 metric atmosphere = 1 kg per sq cm.
1 standard atmosphere = 14.6959 lb per sq in.

TEMPERATURE EQUIVALENTS

To change Centigrade to Fahrenheit—F = 9/5C + 32
To change Fahrenheit to Centigrade—C = (F–32) 5/9

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Unit S-6BL
Technical Data,
Field Service Section,
Air Service Command,
Patterson Field, Fairfield, Ohio.

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Others pertaining to physiology of flight are planned. Wall charts are obtainable from same source as training film (see address above).

COPIFYER LITHOGRAPH CORP., CLEVELAND OHIO
DECEMBER 1942 10,000